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PYROXMANGITE, NEW LOCALITY: IDENTITY OF SOBRALITE AND PYROXMANGITE

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1. SUMMARY

The discovery of a new locality for pyroxmangite provided material for a rather complete study of this little-known triclinic manganese and iron pyroxene, and established Idaho as a second occurrence of the mineral in America. Physical, optical, chemical, and *x*-ray properties of the new mineral show close agreement with those of the mineral from the original locality at Iva, South Carolina. The indices of refraction are slightly lower in the Idaho material, due probably to a correspondingly lower iron content. A careful study of the mineral from Sweden, called sobralite, revealed its identity with pyroxmangite, a name which has four years' priority over sobralite. A comparative study of pyroxmangite with rhodonite (both iron-rich and iron-poor varieties) shows distinct differences in the birefringence and axial angle. *X*-ray patterns indicate a structural difference between the two minerals that, in the light of our present knowledge, justifies the retention of both mineral species. A complete structural analysis, however, may be necessary to establish the definite relationship of pyroxmangite to rhodonite.

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[1] Published by permission of the Secretary of the Smithsonian Institution and the Director of the U. S. Geological Survey.

2. INTRODUCTION

The triclinic iron-manganese silicate, pyroxmangite, from South Carolina, was described in 1913 by Ford and Bradley,[2] and in the intervening period of 22 years has not been reported by this name from any other locality, nor has it been restudied. Although the analysis yielded the same simple metasilicate formula as that of rhodonite, namely, $RSiO_3$ with R chiefly Fe and Mn, and while many of its properties were similar to those of rhodonite, it was held to be an independent species largely because of the much smaller optical angle and its positive optical sign, in contrast to that of rhodonite which generally had been regarded as being negative.

Four years after the published description of pyroxmangite, Palmgren[3] gave the name sobralite to a similar triclinic manganese-iron silicate from Sweden, differing, apparently, from pyroxmangite, only in optical orientation. Both pyroxmangite and sobralite, while having the same metasilicate formula of rhodonite, differ from it chemically in containing from 20 to 28 per cent of FeO, which is a much higher iron content than is reached by any of the known rhodonites, even in the so-called iron-rhodonites. Earlier descriptions of these manganese-iron silicates from Sweden, antedating the publication of the paper on pyroxmangite, apparently confused iron-rich rhodonites with what was later called sobralite. In a recent paper Sundius[4] has greatly clarified the relation of these and other related triclinic manganese silicates.

The pyroxmangite described in this paper was submitted to the United States National Muesum for identification in the summer of 1933 by Mr. E. W. Mortensen of Homedale, Idaho, and shortly after, an additional sample was received from Mr. D. J. Sullivan of Homedale, Idaho, through Dr. George R. Mansfield of the U. S. Geological Survey. It has not been possible to obtain the exact locality of this pyroxmangite. It was first reported as coming from near Homedale and later from near Boise, Ada County, Idaho.

A preliminary examination of the mineral (by E. P. H.) showed that it was a silicate of manganese and ferrous iron, and that it had the general physical and optical properties of pyroxmangite. The minerals associated with it are the black alteration product, skemmatite?, spessartite-almandite garnet ($n=1.799$), granular magnetite, and a small quantity of orthoclase which occurs along the edges of some of the cleavage pieces of the pyroxmangite.

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[2] Ford, W. E., and Bradley, W. M., Pyroxmangite, a new member of the pyroxene group and its alteration product, skemmatite: *Am. Jour. Sci.*, 4th ser., vol. **36**, pp. 169–174, 1913.

[3] Palmgren, John, Die eulysite von Sodermanland (Sobralit): *Bull. Geol. Inst. Upsula*, vol. **14**, p. 173, 1917.

[4] Sundius, Nils, On the triclinic manganiferous pyroxenes: *Am. Mineral.*, vol. **16**, nos. 10 and 11, pp. 411–429, 488–518, 1931.

The discovery of pyroxmangite in Idaho establishes a second occurrence of this mineral in America, and the quantity of material available from this new locality is sufficient to permit an extensive study of its properties. As the optical properties of pyroxmangite from the original locality at Iva, South Carolina, had not been fully determined, this material was restudied. Samples of sobralite from Sweden were obtained from the Roebling collection in the U. S. National Museum, and also from Dr. Nils Sundius of Stockholm, Sweden, and a study of its properties showed it to be identical with the earlier described pyroxmangite.

The writers are greatly indebted to Mr. George L. English, for generously presenting to the U. S. National Museum all of the remaining specimens of pyroxmangite from Iva, South Carolina, which were used in the comparative study; to Dr. Nils Sundius of the Geological Survey of Sweden, for samples of sobralite and for additional information concerning the correction of some published data; to Dr. George Tunell and Mr. C. J. Ksanda of the Geophysical Laboratory, Carnegie Institution of Washington, D. C., for *x*-ray powder photographs and for their discussion of the relation of pyroxmangite to rhodonite. In addition, we are deeply indebted to Dr. James Gilluly of the U. S. Geological Survey, for measurements of the optical orientation of pyroxmangite and sobralite; and to Dr. W. T. Schaller of the U. S. Geological Survey, with whom the authors have had frequent consultations.

3. DESCRIPTION OF MINERAL

Physical Properties

The pyroxmangite from Idaho occurs in cleavage pieces, of which the largest measures about 2½ inches (6.4 cm.) long, 1½ inches (3.8 cm.) wide, and 1 inch (2.5 cm.) thick. When cleaved, the thicker fragments assume forms of short, nearly rectangular prisms, and resemble dull-black blocks.

Like the pyroxmangite from South Carolina, specimens from Idaho are dark brown to black, and have what appears to be a dull sub-metallic luster, due to the prevalence of a film of alteration material. The black opaque coating which has covered the outside and penetrated the small cracks and fractures has produced thereby a false color. After the dark stains have been removed by acid the true color of pyroxmangite is shown to be a pale pink tinged with lilac, while the luster is pearly to vitreous.

Dr. W. T. Schaller of the U. S. Geological Survey kindly made the following goniometric observations and measurements on the cleavages and cleavage angles of pyroxmangite.

"The pyroxmangite from Idaho shows two prominent cleavages, one more perfect than the other, after the prisms *m*(110 and *M*(1$\bar{1}$0). Two additional cleavages can be observed on inspection with a hand lens, and a fifth cleavage was observed while measuring the cleavage angles on the goniometer. The two best cleavages tend to break the mineral into short nearly rectangular prisms and, like the mineral from South Carolina, yield shining faces readily seen on the hand specimen. In order of perfection the five cleavages are:

m(110).—This is a good cleavage, and while the faces are not uniformly a single cleavage surface but an aggregate of many small faces, the best surfaces yield single reflections on the goniometer over a considerable area.

M(1$\bar{1}$0).—The second best cleavage, while good, is not as perfect as the cleavage parallel to *m*(110), and the surfaces generally give multiple reflections on the goniometer. The prismatic cleavage angle is nearly the same as that for the mineral from South Carolina.

b(010).—This cleavage is the "parting" mentioned by Ford and Bradley[5] and has also been noted on the mineral from Sweden. It is much poorer than the prismatic cleavages but is seen repeatedly and was measured on the goniometer. Transverse cracks bisecting the first two cleavages can be observed on some fragments of the mineral when examined with a hand lens.

c(001).—The basal cleavage is not reported on the mineral from South Carolina but can readily be developed on the mineral from Idaho. On the goniometer, a single bright reflection somewhat blurred, is obtained if the cleavage fragment is not too large. The basal cleavage is seen on the cleavage faces of *m*(110) and *M*(1$\bar{1}$0) as transverse, straight-line fractures and is commonly present on crushed fragments when observed under the microscope. Under these conditions it was seen also on fragments from both South Carolina and from Sweden.

a(100).—This very poor cleavage was observed only once on the goniometer. It must be considered doubtful but it is mentioned chiefly because it is recorded by Palache[6] as a parting on rhodonite.

The average angular values obtained on these cleavages are shown in Table 1, to which are added the similar values previously obtained. All measurements, except those for the angle between the two best cleavages, *m*(110) and *M*(1$\bar{1}$0), are poor and not of great accuracy.

The average of several good measurements of the angles *m*(110)

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[5] Ford, W. E., and Bradley, W. M., *op. cit.*, p. 169.

[6] Palache, Charles, The minerals of Franklin Furnace and Sterling Hill, Sussex County, New Jersey: *U. S. Geol. Survey, Prof. Paper* **180,** p. 67, 1935.

TABLE 1. CLEAVAGE ANGLES OF PYROXMANGITE

	Idaho	South Carolina	Sweden
$m(110) \wedge M(1\bar{1}0)$	91°44′	91°50′	91°54′
$b(010) \wedge m(110)$	45 22	45 14	46 —
$b(010) \wedge M(1\bar{1}0)$	43 18	42 56	46 —
$b(010) \wedge a(100)$	96 —	— —	— —
$c(001) \wedge m(110)$	67 —	— —	— —
$c(001) \wedge M(1\bar{1}0)$	84 —	— —	— —
$c(001) \wedge c$-axis[a]	65 —	63 —	63–64

[a] Measured on cleavage faces of *m*(110).

$\wedge M(1\bar{1}0)$, on the pyroxmangite from South Carolina, gave the same value as that found by Ford, namely, 91° 50′. The angle of the Idaho mineral (91° 44′) differs but a few minutes."

The closely-spaced traces of the prismatic cleavage are well developed on some specimens and simulate polysynthetic twinning. The fracture is uneven to hackly. The hardness is 5.5. The specific gravity was determined on a Joly balance as 3.66. The cleavage fragments used in making this determination had been treated with acid to remove the dark stain. The true specific gravity may be slightly higher.

Optical Properties

The mineral when free from manganese oxide and viewed in transmitted light is colorless and nonpleochroic.

The indices of refraction of the pyroxmangite from Idaho are: $\alpha = 1.737$ $\beta = 1.740$, $\gamma = 1.754$; ± 0.001. B=0.017. The axial angle, 2 V, is approximately 39°. Dispersion is moderate $r > v$. Optically positive. These indices of refraction are slightly lower than those for the pyroxmangite from South Carolina, but almost identical with those for the sobralite (pyroxmangite) from V. Silvberg. (See table 4.)

Two good prismatic cleavages and a third transverse (basal) cleavage, that makes an angle of 65° with the *c*-axis on the *m*(110) cleavage, were frequently observed on crushed fragments under the microscope. These observations were later confirmed by goniometric methods. The extinction angle on $m(110) = 31°$.

The optical orientation of the mineral is given in detail in the section devoted to the discussion of the relation of sobralite from Sweden to pyroxmangite. It will suffice here to say that allowing for a slight variation in chemical composition, and for errors of adjustment and measurement, there is no essential difference between the optical orientations of pyroxmangite from Idaho and South Carolina, and the mineral from Sweden (sobralite).

In the pyroxmangite from Idaho the axial plane makes an angle of about 45° to *m*(110) and 89° to *M*($1\bar{1}0$).

Chemical Composition

The mineral fuses with difficulty to a black magnetic bead when heated in the blow pipe flame. The unaltered material is not attacked by acids. According to Schaller[7] rhodonite is partially decomposed (about 10 per cent) by HCl.

The sample analyzed was carefully prepared, first by crushing and screening to remove all fine powder, then by treating it with sulphurous acid to remove the dark stains. After washing with water and drying in air the material was hand picked and only the grains with a bright luster were selected for the analysis.

TABLE 2. ANALYSIS AND RATIOS OF PYROXMANGITE FROM IDAHO
[E. P. Henderson, analyst]

	Analysis	Ratios		
SiO_2	45.47	.7566	.7566	1.00
MnO	27.06	.3815	.7629[a]	1.01
FeO	20.91	.2910		
CaO	2.62	.0467		
MgO	2.14	.0531		
Fe_2O_3	1.50	.0094	.0094	
H_2O	0.32			
	100.02			

[a] After deduction of .0094 FeO corresponding to .0094 Fe_2O_3 for magnetite.

The sample analyzed contained, as its only impurity, specks of disseminated magnetite, amounting to 2.18 per cent, if all the Fe_2O_3 be regarded as belonging to magnetite. In the calculated ratios, shown with the analysis, a corresponding deduction of 0.68 per cent of FeO is made.

The ratios conform closely to the metasilicate formula $RO \cdot SiO_2$ or $RSiO_3$ with R essentially Mn and Fe, and a little Mg and Ca. The formula for pyroxmangite from Idaho can then be written: $(Mn, Fe)SiO_3$. Its ratio of MnO:FeO (after allowing for magnetite) is 0.3815:0.2816, or about 4:3.

In the pyroxmangite from South Carolina, however, iron oxide slightly dominates over manganese oxide.

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[7] Personal communication.

The calculated weight percentages of the four components in the pyroxmangite from Idaho are as follows:

$MnSiO_3$	51.0
$FeSiO_3$	38.0
$MgSiO_3$	5.4
$CaSiO_3$	5.6
	100.0

Alteration

The alteration product of the Idaho pyroxmangite is similar in appearance to that of the South Carolina material, which was described by Ford and Bradley[8] and named skemmatite. Although the brown to black alteration product on the Idaho material is developed to a less extent than on the South Carolina material, it covers the specimens and penetrates the small fractures throughout the mass, and is a conspicuous and characteristic associated material of the pyroxmangite from both localities. This altered material can be removed readily by treatment with hydrochloric or sulphurous acid.

It was found that the Fe_2O_3: MnO_2 ratios in the altered product on the Idaho material are not very close to the values reported on the S. Carolina mineral. There is not enough of the altered product on the Idaho specimens of pyroxmangite to satisfactorily determine the composition of skemmatite. The results are, on the other hand, close enough to somewhat strengthen the status of this mineral. However, when and if specimens are obtained which will permit a study of the composition of skemmatite, an investigation will be made.

4. PYROXMANGITE FROM IVA, SOUTH CAROLINA

The optical properties of the pyroxmangite from South Carolina were only partially determined by Ford and Bradley[9] who gave the mean index as 1.75 or 1.76; the optical angle as 30°; positive sign. Because of the lack of crystal faces the exact orientation of the cleavage pieces was impossible, therefore the position of the extinction direction was regarded as uncertain.

The physical and optical properties of pyroxmangite from Idaho and from Iva, South Carolina, are very similar. The indices of refraction are slightly lower in the mineral from Idaho, corresponding to a smaller percentage of FeO. The tabulation of the properties and composition of the mineral from Iva, South Carolina, is shown in Tables 4 and 7, which also include similar data for the pyroxmangite (sobralite) from the two localities in Sweden. These values show the essential identity of the mineral from Idaho with that from the original locality of pyroxmangite in South Carolina.

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[8] Ford, W. E., and Bradley, W. M., *op. cit.*, p. 174.

[9] Ford, W. E., and Bradley, W. M., *op. cit.*, pp. 170–171.

5. IDENTITY OF SOBRALITE WITH PYROXMANGITE

Four years after the description of pyroxmangite was published, the mineral called sobralite was announced. (For convenience of reference pyroxmangite from Sweden is referred to as sobralite in this paper.) Sobralite has been found in two neighboring localities in Sweden, namely, Vester Silvberg and Tunaberg. V. Silvberg is the name of a mining district in the southern part of the province of Dalecarlia, central Sweden. The same district is also named Stollbery after the principal mining camp. Tunaberg is located in the province of Södermanland, SW of Stockholm (more exactly located about 14 km. SSW of Nykoping).

Pyroxmangite and the mineral called sobralite are so closely related in their chemical composition and in their optical properties that the study of pyroxmangite naturally involved the study of sobralite. The mineral sobralite was named by Palmgren[10] when making a study of the eulysite of Södermanland, Sweden. This mineral was studied optically by Sobral, who described it as being a triclinic pyroxene, optically positive, colorless, and without noticeable pleochroism in thin sections. Palmgren gave to this "hitherto unknown variety of pyroxene" the name sobralite, in honor of his former teacher, Doctor José M. Sobral of Buenos Aires.

Later Sobral[11] added the following descriptions:

"The mineral is triclinic. The crystals are anhedral. Twinning does not appear. The cleavages on 110 and $1\bar{1}0$ are commonly rather indistinct; interrupted cleavage cracks bisecting the prismatic cleavages also exist. Thin sections of more than 0.05 mm. thickness are not pleochroic. In the case of very low magnification the mineral shows a faint lilac color. The sign is positive (+). $2V=41.1°$; $r>v$ strong, but weaker than in the case of iron rhodonite. $\beta-\alpha=0.0025$; $\gamma-\beta=0.0175$; $\gamma-\alpha=0.0200$. The mean index is about 1.74."

Sobral mentions as the associated minerals, diopside, a triclinic pyroxene, olivine, and spessartite.

Sundius[12] has discussed the investigations of Sobral and Palmgren, and was able to obtain some of the material on which Sobral had worked and from this material prepared a sample for a new analysis (No. 4, Table 7).

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[10] Palmgren, J., *Bull. Geol. Inst. Upsula*, vol. **14**, p. 173, 1917.

[11] Sobral, José M., Optical investigation of the new pyroxene sobralite: *Bull. Geol. Inst. Upsula*, vol. **18**, p. 47, 1921.

[12] Sundius, Nils, *op. cit.*, pp. 502–507.

Palmgren, Sobral, and Sundius, all recognized the similarity of sobralite and pyroxmangite, but the information on the optical properties and orientation of pyroxmangite, as described by Ford and Bradley, was apparently too incomplete to establish identity.

A mineral designated as an iron-rich rhodonite from Vester Silvberg, Sweden, was described by Weibull[13] in 1884. Sundius secured two thin sections made from the specimen collected by Weibull, and after examining them reported that the "iron-rhodonite" had the same optical properties as the sobralite from Tunaberg. On the basis of both optical and chemical similarity to sobralite, Sundius called the "iron-rhodonite" analyzed by Weibull, sobralite. No. 3, Table 7, shows the analysis made by Weibull.

The sobralite specimen from Södermanland, Sweden, in the U. S. National Museum Collection (R-3128), was studied by the authors of this paper, and the optical properties of the sobralite and of the minerals found intimately associated with it, are given below. The minerals were separated by heavy solution and studied in grains mounted in immersion oils and melts. A thin section was also cut from this same specimen and examined optically.

About three-fourths of the specimen is composed of sobralite and a monoclinic pyroxene, the latter predominating. The sobralite is triclinic, optically positive, $2V=40°$. Indices of refraction are, $\alpha=1.726$, $\beta=1.728$, $\gamma=1.744$. $B=0.018$. The pyroxene is related optically to schefferite. It is optically positive, 2V large, with indices of refraction: $\alpha=1.701$, $\beta=1.705$ $\gamma=1.730$. $B=0.029$.

About one-fifth of the sample is composed of spessartite, $n=1.798$. The remaining fraction of the sample consists of knebelite, optically negative, $2V=60°$, indices of refraction: $\alpha=1.805$, $\beta=$n.d., $\gamma=1.845$; bustamite, optically negative, $2V=60°$, indices of refraction: $\alpha=1.660$, $\beta=1.670$, $\gamma=1.674$; and apatite, optically negative, indices of refraction: $\epsilon=1.63$, $\omega=1.64$.

The properties of the sobralite (U.S.N.M. No. R-3128) and its associated minerals agree very well with those described by Palmgren and by Weibull.

Sundius kindly contributed a sample and thin section of the sobralite from Vester Silvberg on which he had made his studies.[14] This specimen was also examined optically and the values found by the authors are: Optically positive, $2V=41°$, dispersion $r>v$, indices of refraction: $\alpha=1.737$, $\beta=1.740$, $\gamma=1.755$, $B=0.018$. These values all agree within the limits of error of measurement with those reported by Sundius. The optical properties of the sobralite from Vester Silbverg coincide also within the limits of error of measurement with those of the pyroxmangite from Idaho.

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[13] Weibull, M., *Kungl. Vet. Akad. Övers.*, no. 9, p. 29, 1884.

[14] Sundius, N., *op. cit.*, pp. 502–505, 518.

The properties of pyroxmangite and sobralite from the different localities are summarized in Table 4. It can easily be seen that the properties of all of these minerals are essentially identical. The minor variations, as in the absolute values of the indices of refraction, are due to the varying ratios of MnO and FeO, and in some measure to the variations in CaO and MgO.

Table 4. Properties of Pyroxmangite and of Sobralite, Showing their Identity

Mineral	Pyroxmangite		Sobralite from Sweden				
Locality	Idaho	South Carolina	V. Silvberg		Tunaberg (Södermanland)		
Data by	Glass	Glass	Sundius	Glass	Glass	Sobral	Sundius
System	Tricl.	Tricl.	Tricl.	Tricl.	Tricl.	Tricl.	Tricl.
Cleavage	*m, M, b, c*	*m, M, b, c*	*m, M, c*	*m, M, b, c*	*m, M, b, c*	*m, M, b*	*m, M*
$m:M$	91°44′	91°50′	92°12′	—	—	91°54′	92°
$m:b$	45°22′	45°14′	—	—	—	46°	—
$M:b$	43°18′	42°56′	—	—	—	46°	—
$\overset{\mid}{c}:c^{a}$	65°[a]	63°[a]	About 70°[b]	64°[a]	63°[a]	—	—
α	1.737	1.748	1.738	1.737	1.726	—	—
β	1.740	1.750	1.740	1.740	1.728	1.74[c]	—
γ	1.754	1.764	1.755	1.755	1.744	—	—
$\gamma-\alpha$	.017	.016	.017	.018	.018	.020	.018
$\gamma-\beta$	.014	.014	.015	.015	.016	.017	.015
$\beta-\alpha$	.003	.002	.002	.003	.002	.003	.003
Sign	+	+	+	+	+	+	+
2 V	39°	37°	42°	41°	40°	41°	41°
Disp.	$r>v$	$r>v$	—	$r>v$	$r>v$	$r>v$	—

[a] As measured on the cleavage after *m*(110).

[b] Given by Weibull as angle between (001) and prismatic cleavage. Also noted by Sundius.

[c] Mean index of refraction.

The optical orientations of the mineral from Idaho, and for comparison, also from Iva, South Carolina, and from V. Silvberg, Sweden, were kindly determined by Dr. James Gilluly of the U. S. Geological Survey, using the Fedorov universal stage. Dr. Gilluly reports as follows.

"The optical orientations of the mineral from V. Silvberg, Sweden, Idaho, and South Carolina, were determined in thin sections using the universal stage, with the prismatic cleavages $m(110)$ and $M(1\bar{1}0)$ as reference planes. Owing to twinning and slight displacements in parts of even small cleavage fragments, the material examined was not satisfactory for accurate measurements. This was especially true for the pyroxmangite from South Carolina, which showed commonly only one prismatic cleavage and a second cleavage considered as parallel to the base $c(001)$. The second prismatic cleavage however was observed frequently enough to make the control of orientation seem reasonably good.

"The accompanying stereographic projection (Fig. 1) embodies the results of the measurements. Only one cleavage fragment from each locality was measured and no color filters were used. The measurements of the positions of α, β, and γ for the mineral from the three localities cannot be considered accurate within less than 10 degrees. Nevertheless, they suffice to establish the close similarity in optical orientation of the three specimens. The coordinates measured are given in Table 5, to which have been added the more accurate determinations of Sundius[15] on the sobralite from V. Silvberg (analysis No. 4 in Table 7) and from Tunaberg (not analyzed).

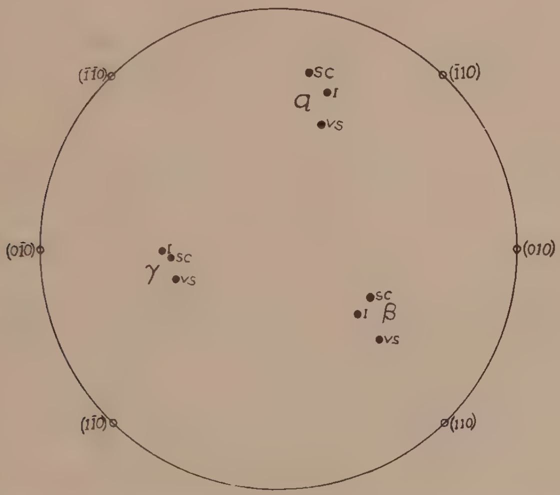

FIG. 1. Stereographic projection of positions of the three principal optical directions α, β, and γ for the three occurrences of pyroxmangite. VS = V. Silvberg, Sweden (sobralite), I = Idaho, SC = South Carolina.

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[15] Sundius, N., *op. cit.*, pp. 505, 507, 1931.

TABLE 5. COORDINATES OF THE OPTICAL DIRECTIONS α, β AND γ IN PYROXMANGITE AND IN SOBRALITE

ϕ (Measured from $m(110)$)	α	β	γ
V. Silvberg (Sundius)	18.7°(±1°)	266°(±1.5°)	136.6°(±2.6°)
Tunaberg (Sundius)	14.2°(±5.4°)	264.7°(±4°)	136.9°(±5.1°)
V. Silvberg (Gilluly)	26°(±10°)	274.5°(±10°)	152°(±10°)
Idaho (Gilluly)	28°(±10°)	276°(±10°)	137°(±10°)
So. Carolina (Gilluly)	36°(±10°)	288.5°(±10°)	140°(±10°)
ρ	α	β	γ
V. Silvberg (Sundius)	60.9°(±0.9°)	53.7°(±2°)	48.5°(±1.4°)
Tunaberg (Sundius)	62.2°(±4°)	56.5°(±6.7°)	46.2°(±5.8°)
V. Silvberg (Gilluly)	57°(±10°)	59°(±10°)	48.5°(±10°)
Idaho (Gilluly)	69°(±10°)	46.5°(±10°)	52°(±10°)
So. Carolina (Gilluly)	73.5°(±10°)	46.5°(±10°)	48.5°(±10°)

"The agreement in the optical orientation, as given in Table 5, is sufficiently close to confirm the essential identity of the mineral from the different localities. The discrepancies can be ascribed to the difficulty of making accurate measurements on the not very satisfactory thin sections, the notable dispersion, and the somewhat variable chemical composition of the mineral from the three localities, not only in percentages of the essential components $FeSiO_3$ and $MnSiO_3$ but also in that of the minor components $CaSiO_3$ and $MgSiO_3$, as given in Table 7.

TABLE 6. ANGLES BETWEEN THE PRINCIPAL OPTICAL PLANE (α, γ) AND THE PRISMATIC CLEAVAGES

	$(\alpha, \gamma)\wedge m\{110\}$	$(\alpha, \gamma)\wedge M\{1\bar{1}0\}$
V. Silvberg (Sundius)	35.5°	84.5°
Tunaberg (Sundius)	32.5°	83.5°
Tunaberg (Sobral)	36°	84.2°
V. Silvberg (Gilluly)	32°	88°
Idaho (Gilluly)	44.5°	87°
So. Carolina (Gilluly)	47°	78°

"These data yield the following angles (Table 6) between the principal optical plane (α, γ) and the prismatic cleavages. The values determined by Sobral on sobralite from Tunaberg as given by Palmgren[16] are added.

"It is evident that the optical orientation, first correctly determined by Sobral, is nearly the same for the mineral from the different localities. The greatest variation from the general average is shown by the pyroxmangite from South Carolina. This occurrence has the highest content of $FeSiO_3$ of any of the pyroxmangites (based on a single analysis and assuming that all the South Carolina pyroxmangite is homogeneous in composition), and the slight deviations of the values for the optical orientations from the general average (including the maximum values of the indices of refraction) may well be a function of the content of the iron component.

"Palmgren[17] assumed an established difference in optical orientation between the Swedish mineral he named sobralite, and the pyroxmangite from South Carolina, emphasizing the supposed difference by contrasting the two orientations in his Figs. 1 and 2 (p. 178). In the original description of pyroxmangite it is stated[18] that the optic axial plane is normal to the parting plane *b*(010). Had an examination of pyroxmangite been made at the time and by the same methods used on sobralite, it would have been seen that such an orientation was not correct and the only apparent difference between sobralite and pyroxmangite would have disappeared. For a triclinic mineral with no crystal faces and only cleavages as a guide to the orientation it is obviously extremely difficult to determine the correct optical orientation without the use of the universal stage."

The following table contains all of the analyses of pyroxmangite and of sobralite in the literature, including the new pyroxmangite described in this paper. Analyses of mixtures of sobralite and iron-rhodonite are not considered. Following the table of analyses is the calculated weight percentages of the components.

In the four analyses, $MnSiO_3$, is greater than $FeSiO_3$ in two and less than $FeSiO_3$ in the other two. It cannot be said, therefore, that either component dominates in pyroxmangite. The quantities of $CaSiO_3$ and of $MgSiO_3$ are similar to those in the rhodonites.

The indices of refraction of the pyroxmangite (sobralite) from Södermanland are about as much lower than those for the mineral from V. Silvberg and from Idaho as those of pyroxmangite from South Carolina

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[16] Palmgren, J., *op. cit.*, p. 175.

[17] Palmgren, J., *op. cit.*, pp. 177–179.

[18] Ford, W. E., and Bradley, W. M., *op. cit.*, p. 170.

Table 7. Chemical Analyses of Pyroxmangite and Sobralite.

		1	2	3	4
SiO_2		45.47	47.14	45.12	46.53
MnO		27.06	20.63	24.25	20.50
FeO		20.91	28.34	22.44	24.69
CaO		2.62	1.88	5.62	5.46
MgO		2.14	—	1.20	1.39
Fe_2O_3		1.50	—	—	0.85
Al_2O_3		none	2.38	1.38	0.21
H_2O		0.32	0.33	—	0.39
BaO		—	—	—	0.08
		100.02	100.70	100.01	100.10
Component composition	$MnSiO_3$	51	41	44	39
	$FeSiC_3$	38	55	41	46
	$CaSiO_3$	6	4	12	12
	$MgSiO_3$	5	0	3	2
		100	100	100	100

1. Pyroxmangite, Idaho. Analyst, E. P. Henderson.
2. Pyroxmangite, Iva, South Carolina. Analyst, W. M. Bradley.
3. Sobralite, ("iron rhodonite"), V. Silvberg, Sweden. Analyst, M. Weibull.
4. Sobralite V. Silvberg, Sweden. Analyst, A. Bygdén.

are higher. The pyroxmangite from South Carolina with the highest indices of refraction, has the highest percentage of $FeSiO_3$. The indices of refraction of the pyroxmangite from Idaho are nearly identical with those of the pyroxmangite (sobralite) from V. Silvberg.

The average percentage ratio of $MnSiO_3$ to $FeSiO_3$ in the four analyses is 44:45, and it may be that pyroxmangite approaches a double salt of the formula $MnO \cdot FeO \cdot 2SiO_2$ in composition.

6. *X*-ray Powder Photographs

The *x*-ray powder photograph of sobralite from V. Silvberg, Sweden, is identical with those of pyroxmangite from Idaho and from South Carolina. The pattern of the sobralite from Sweden is No. 3 in Fig. 3, Nos. 1 and 2 being the patterns of pyroxmangite from Idaho and South Carolina. The remaining three patterns (nos. 4, 5, and 6) shown in Fig. 3 are those of rhodonite. The relation of these two minerals is discussed in later pages.

These *x*-ray powder photographs[19] of pyroxmangite as well as those of rhodonite were made by Dr. George Tunell and Mr. C. J. Ksanda of the Geophysical Laboratory, Carnegie Institution of Washington, D.C.

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[19] These *x*-ray films are on record in the reference files of the Geophysical Laboratory, Carnegie Institution of Washington, D.C.

The physical and optical properties, chemical composition, and *x*-ray patterns of pyroxmangite and sobralite are so nearly identical that it is evident that they represent the same mineral.

7. Relationship of Pyroxmangite to Rhodonite

The foregoing study of pyroxmangite and sobralite brings out certain characteristics that raise the question as to its relationship to rhodonite. It, therefore, seems advisable to include a comparison of these two minerals as a part of this paper.

Both pyroxmangite and rhodonite are triclinic minerals with similar properties and chemical compositions. Rhodonite is a metasilicate composed dominantly of $MnSiO_3$, with a maximum recorded content of 14.5 per cent of FeO, corresponding to 27 per cent of $FeSiO_3$. Pyroxmangite is a similar metasilicate with percentages of FeO from 20.9 to 28.3, corresponding to 38 to 55 per cent of $FeSiO_3$. Do these relations imply that rhodonite and pyroxmangite are parts of an isomorphous series, and if so, do the so-called iron rhodonites occupy an intermediate position?

Several valuable papers on rhodonite[20] have recently been published, and numerous chemical analyses are available, but a comparison with pyroxmangite indicates the necessity of a critical study of the rhodonites low and high in ferrous iron. For this comparison a rhodonite from Bald Knob, North Carolina, previously described by Ross and Kerr,[21] was selected as a low-iron member. A new sample from this locality was analyzed in order that ample material might be available for detailed study of all of the properties. An iron-rich rhodonite from Broken Hill, New South Wales, Australia,[22] was selected as a representative high-iron type. The chemical analyses (by E. P. H.) and optical properties (by J. J. G.) of these two rhodonites are given in Table 8 together with the rhodonite richest in iron from Tuna Hästberg, Sweden, described by Sundius,[23] and the two pyroxmangites containing the minimum and maximum percentages of FeO.

The compilation (Table 8) shows that in rhodonite with a range of FeO content from 2.44 to 14.51 per cent, there is almost no variation in

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[20] Hey, M. H., The variation of optical properties with chemical composition in the rhodonite-bustamite series: *Mineral, Mag.*, vol. **22**, no. 127, pp. 193–205, 1929.

Sundius, N., *op. cit.*, pp. 488–489; pp. 501–502; and pp. 517–518, 1931.

[21] Ross, C. S., and Kerr, Paul F., The manganese minerals of a vein near Bald Knob, North Carolina: *Am. Mineral.*, vol. **17**, pp. 13–15, 1932.

[22] U. S. National Museum Collection (U.S.N.M. No. 90102).

[23] Sundius, N., *op. cit.*, pp. 501–502; pp. 517–518, 1931.

Table 8. Analyses and Indices of Refraction of Selected Rhodonites and Pyroxmangites, with Varying Percentages of FeO.

		Rhodonite			Pyroxmangite	
		Bald Knob, N.C.	Broken Hill, N.S.W.	Tuna Hästberg, Sweden	Idaho	Iva, S.C.
SiO_2		45.17	46.45	47.78	45.47	47.14
MnO		45.98	35.10	29.20	27.06	20.63
FeO		**2.44**	**12.65**	**14.51**	**20.91**	**28.34**
MgO		1.31	0.40	1.93	2.14	—
CaO		4.10	5.45	6.55	2.62	1.88
Al_2O_3		—	—	0.08	none	2.38
Fe_2O_3		0.93	0.12	0.11	1.55	—
H_2O		0.30	0.27	0.09	0.32	0.33
		100.23	100.44	100.25	100.02	100.70
Component composition	$MnSiO_3$	82	65	53	51	41
	$FeSiO_3$	5	23	26	38	55
	$CaSiO_3$	9	11	15	6	4
	$MgSiO_3$	3	1	6	5	0
		100	100	100	100	100
Sp Gr.		3.75	3.68	3.65	3.66	3.80
α		1.724	1.726	1.725	1.737	1.748
β		1.728	1.730	1.728	1.740	1.750
γ		1.737	1.739	1.737	1.754	1.764
B		.013	.013	.012	.017	.016
2V		70°	74°	70°	39°	37°

the values of the indices of refraction or of the axial angle. There is, however, a decided discontinuity in these values where those of pyroxmangite are considered. The change in the values for the axial angles between the two minerals is striking.

In the course of a study of johannsenite Dr. W. T. Schaller[24] has compiled the available data on rhodonite, where the optical properties are correlated with chemical composition. In the following table the average values of the birefringence and axial angle are given and correlated with the iron content.

Table 9 shows that the average birefringence of low-iron rhodonite is

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[24] Personal communication.

TABLE 9. AVERAGE BIREFRINGENCE (B) AND AXIAL ANGLE (2V) FOR RHODONITE AND PYROXMANGITE

	Ave. percentage of FeO	B	2V
Average value of B for 10 rhodonites, and of 2V for 9 rhodonites, excluding 2 iron-rich rhodonites	1.54	0.013	71°
Average values for 2 iron-rich rhodonites	13.58	0.013	71°
Average values for 4 pyroxmangites	24.10	0.018	40°

identical with that of the high-iron rhodonite, notwithstanding the fact that the two iron-rich varieties have an average FeO content more than half the average FeO content of 4 pyroxmangites. Therefore, the high-iron rhodonites do not occupy an intermediate position between pyroxmangite and low-iron rhodonites. The axial angle (2V) of rhodonite ranges from 76° down to 63°, with a considerable gap between that and the highest value (42°) for pyroxmangite.

The birefringences of the various rhodonites are rather constant. Schaller's compilation of 12 rhodonites gives 0.013 as the average value. This corresponds closely with the average value of 0.0126 of the 13 determinations given by Sundius.[25] The birefringence of analyzed rhodonite is shown in the following tabulation, compared with that of pyroxmangite.

TABLE 10. BIREFRINGENCE OF ANALYZED RHODONITE AND OF PYROXMANGITE

Rhodonite	Pyroxmangite
0.011 (one determination)	0.016 (one determination)
0.012 (four determinations)	0.017 (two determinations)
0.013 (four determinations)	0.018 (three determinations)
0.014 (two determinations)	0.020 (one determination)
0 016 (one determination)	
0.013 (average)	0.018 (average)

Only one determination of rhodonite exceeds 0.014 and this single high value of 0.016 is probably too high as the 13 acurate determinations given by Sundius range from 0.0118 to 0.014, with no value as high as 0.016.

The indices of refraction of analyzed rhodonite range between the values for α of 1.711 to 1.738, and values for γ of 1.724 to 1.751. These are in general lower than those of pyroxmangite which has values for α ranging between 1.726 and 1.748, and values for γ between 1.744 and 1.764. The values of the indices of refraction, birefringence, and axial angle for pyroxmangite and for rhodonite are shown graphically in Fig. 2 where the indices of refraction are plotted in the order of increasing values for the index β.

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[25] Sundius, N., *op. cit.*, pp. 489–502, 1931.

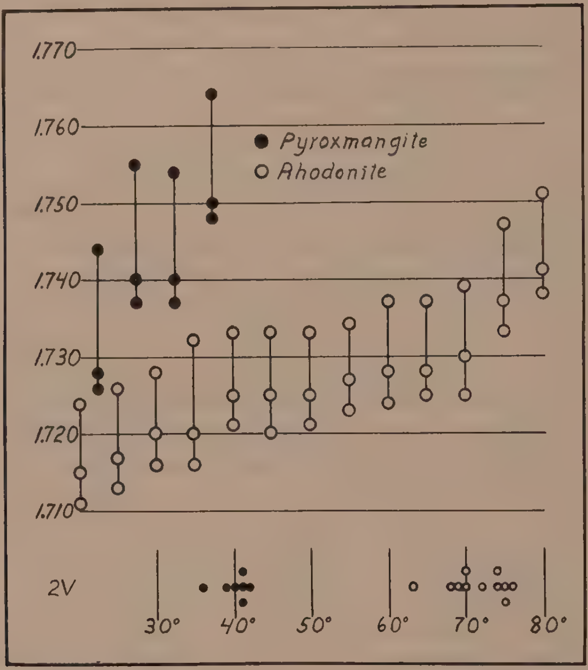

FIG. 2. Indices of refraction, birefringence, and axial angle of pyroxmangite and of rhodonite.

The foregoing comparative study shows that the pyroxmangite series has a slightly higher value for the indices of refraction than the rhodonite series; there is even more marked difference in birefringence between these two minerals; and there is a considerable gap from the highest value for the axial angle of pyroxmangite and the lowest value of rhodonite. These facts strongly suggest that these two minerals do not represent a series of continuously variable components.

The chemical constituents of rhodonite are the same as those of pyroxmangite. So far no rhodonite has been described in which the content of FeO is much greater than about half the average value for pyroxmangite.

The other constituents, CaO and MgO (and in the variety fowlerite, ZnO), are subordinate and of about the same order of importance as they are in pyroxmangite. There apparently is no component in rhodonite which might enter into its composition which would tend to lower the axial angle to within the range for pyroxmangite, or change the other optical properties in closer agreement with those of pyroxmangite.

The close relation between the morphology of rhodonite and pyroxmangite, as expressed by cleavage angles, is shown in the following table.

TABLE 11. COMPARISON OF CLEAVAGE ANGLES OF RHODONITE AND PYROXMANGITE

Angle	Rhodonite	Pyroxmangite
$m(110) \wedge M(1\bar{1}0)$	92°29′	91°47′[a]
$b(010) \wedge m(110)$	45 53	45 18 [a]
$b(010) \wedge M(1\bar{1}0)$	41 39	43 07 [a]
$b(010) \wedge a(100)$	94 26	96[b]
$c(001) \wedge m(110)$	68 45	67[b]
$c(001) \wedge M(1\bar{1}0)$	86 23	84[b]
$\phi(001)$	58 08	62 16[b]
$\rho(001)$	21 46	24 59[b]

[a] Average of angles for pyroxmangite from Idaho and South Carolina.
[b] Measured on material from Idaho.

The comparison of the cleavages of the two minerals is as follows, the data for rhodonite being taken from Palache.[26]

	Pyroxmangite	Rhodonite
$m(110)$	Perfect	Perfect
$M(1\bar{1}0)$	Good	Perfect
$b(010)$	Fair	Very good parting
$c(001)$	Fair	Good
$a(100)$	Very poor	Traces (parting)

In color (when freed from stain) and hardness the two minerals are very similar. Both are triclinic and optically positive. The specific gravity of rhodonite (3.65–3.75) is slightly less than that for pyroxmangite (3.66–3.80).

It was hoped that a comparison of the *x*-ray powder photographs of the two minerals would yield conclusive evidence of their identity or non-identity. This hope was not fully realized but the following statement of Dr. Tunell[27] would seem to support the conclusion reached by a

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[26] Palache, C., *op. cit.*, p. 67.

[27] Personal communication, dated January 8, 1935.

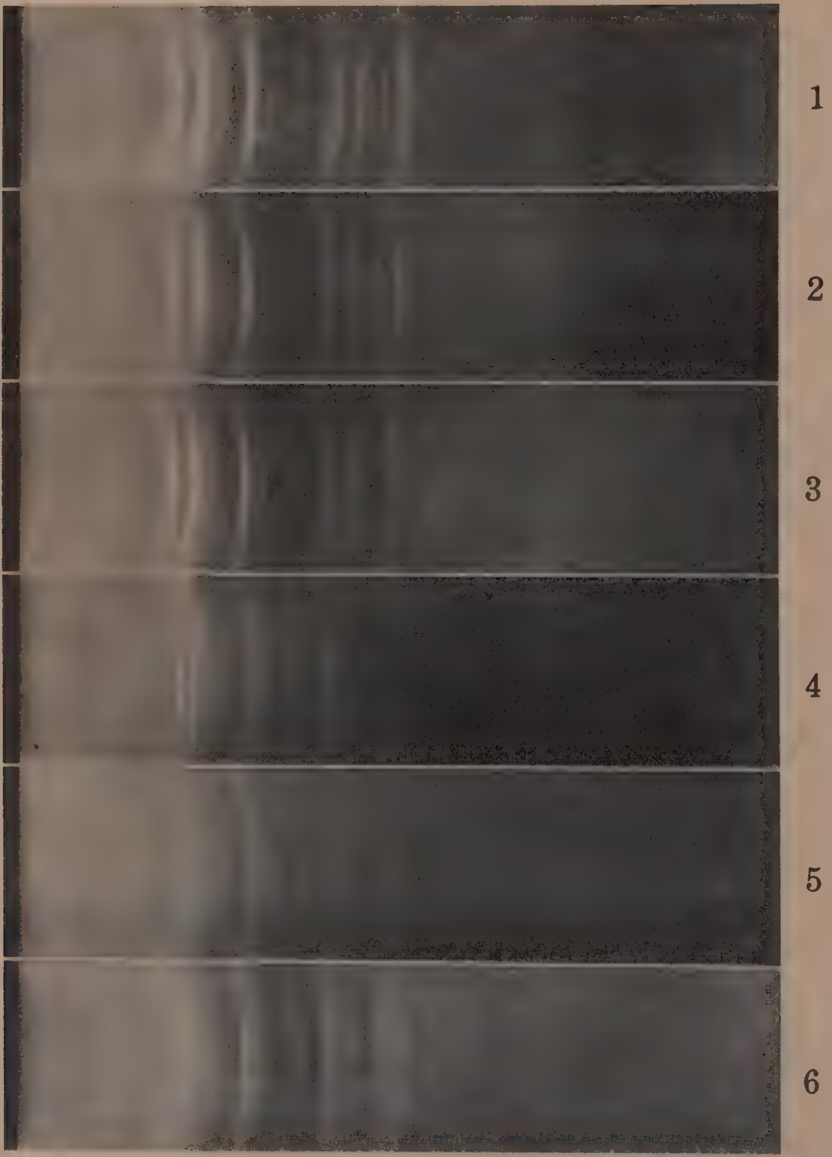

FIG. 3. *X*-ray powder photographs of pyroxmangite and rhodonite.

No. 1. Pyroxmangite from Idaho.
No. 2. Pyroxmangite from South Carolina.
No. 3. Pyroxmangite (sobralite) from V. Silvberg, Sweden.
No. 4. Iron-rhodonite from Broken Hill, N.S.W.
No. 5. Rhodonite from Bald Knob, N.C.
No. 6. Rhodonite from Franklin, N.J.

comparison of the optical properties of the two minerals, namely, that pyroxmangite and rhodonite are distinct species, and do not belong to a single continuously variable series.

The x-ray patterns of pyroxmangite from Idaho, South Carolina, and Sweden (sobralite), are shown in Fig. 3 as Nos. 1, 2, and 3. The iron-rich rhodonite from Broken Hill, N.S.W., follows (No. 4), and the last two pictures are of iron-poor rhodonite from Bald Knob, N.C. (No. 5), and from Franklin, N.J. (No. 6).

Dr. Tunell's statement of the comparison of the x-ray patterns of pyroxmangite and of rhodonite follows:

" . . . The powder photographs of pyroxmangite and rhodonite show a great similarity which suggests (although it does not prove) a close structural relationship between the two. The question that has been raised is whether or not pyroxmangite and rhodonite belong to the same solid solution series, that is, to a single phase of continuously variable composition. If this were the case, and atoms of iron were substituted for atoms of manganese in pyroxmangite (the atoms of iron in pyroxmangite occupying the same equipoints on which the atoms of manganese are situated in rhodonite), no differences in the intensity of the lines would be expected because the scattering power of magnanese is practically identical with that of iron. Some differences in spacings might be brought about by the substitution of iron for manganese, however, since the atomic radii of iron and manganese differ a little. Actually, one finds on the films that the lines have slightly different spacing in pyroxmangite and rhodonite but that the intensities are closely similar. Certainly the observed differences in the intensities are not great enough to prove that pyroxmangite and rhodonite do not belong to the same solid solution series. The evidence of the spacings suggests to me that there is an appreciable difference between pyroxmangite and rhodonite, which difference is not covered by a continuous change from one to the other. This evidence concerns the first two strong lines in the powder spectrum. The spacing of these two lines in the two pyroxmangites from Idaho and South Carolina are the same within the error of measurement. Likewise the spacings of these two lines in the three samples of rhodonite from Franklin Furnace, N.J., Bald Knob, N.C., and Broken Hill, New South Wales, are the same within the error of measurement. The spacing of the innermost strong line in both samples of pyroxmangite is the same as that in the samples of rhodonite. But the spacing of the second strong line in both samples of pyroxmangite is appreciably different from that in all the samples of rhodonite. It seems that if the presence of 21–28 per cent of FeO in pyroxmangite were responsible for this shift, an intermediate position of the line would be observed in the case of the iron rhodonite from Broken Hill which contains nearly 13 per cent of FeO as compared with the almost pure manganese rhodonite. In other words, the hypothesis of solid solution would call for a continuous shift of the line with variation of composition, whereas the shift does not seem to be continuous. It would not be safe to base a definite conclusion on such meager evidence however, and from our point of view the question of exact relationship between pyroxmangite and rhodonite cannot be settled definitely as yet. Perhaps a complete structural analysis will be necessary in order to throw the desired light on this problem."

MICROSCOPE WITH UNIVERSALLY MOVABLE TUBE

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Introduction

A microscope with universally movable tube has been designed in order to facilitate the examination of crystal grains of varying orientations for the determination of their refractive indices, using the dispersion method.[1] The Fedorov universal stage, which is extremely useful for the examination of mounted mineral sections, is not suitable for the examination of mineral grains immersed in a liquid[2] as the liquid will flow and the grains shift their positions upon inclining the stage. The device of a movable microscope tube aims primarily to apply the methods of the universal stage to grains immersed in a liquid.

Construction of the Instrument

The main parts of the instrument are as follows:

(A) Main circle, 29 cm. in diameter, carrying the microscope tube with its optical parts attached, and the illuminator.

(B) Semi-circle, within which the main circle (A) rotates.

(C) Horizontal stage.

(D) Supporting base.

(A) The main circle is graduated on the side and reads with the aid of a vernier to tenths of a degree. About 5 cm. of the circle is cut away, and in this space is placed a semi-circular arc (a_1), which carries the microscope tube. Opposite to (a_1) is fastened a support (a_2) with an adjustment screw for the illuminating apparatus. Below the polarizer is a cylindrical case with a lamp. This can be replaced with a mirror by means of which light from an outside source (e.g., from a monochromator) may be used.

(B) The main circle (A) is supported by the semi-circle B, and is rotated within it by means of a rack and pinion. Also the semi-circle B can be rotated about the horizontal axis d_1d_2.

(C) The circular stage, 12.5 cm. in diameter, is graduated and reads with the aid of a vernier to tenths of a degree. The central portion, about 5.5 cm. in diameter, can be removed when the hemi-spherical glass segment is used. The center of rotation of the stage can be made to coincide with that of the main circle ring (A) by adjusting screws.

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[1] Merwin, H. E., and Ponsjak, E., *Jour. Am. Chem. Soc.*, vol. **64**, p. 1965, 1922.
Tsuboi, S., *Mineral. Mag.*, vol. **18**, p. 108, 1923.
Tsuboi, S., *Japanese Jour. Geol. and Geography*, vol. **3**, p. 19, 1924.
Tsuboi, S., *Jour. Geol. Soc. Tokyo*, vol. **37**, p. 37, 1930.

[2] Emmons, R. C., *Am. Mineral.*, vol. **14**, p. 441, 1929.
Lindley, *Min. u. Petr. Mitt.*, vol. **41**, p. 58, 1930.

(D) The base is constructed with stout vertical arms, which carry the above mentioned parts A, B, and C at d_1 and d_2.

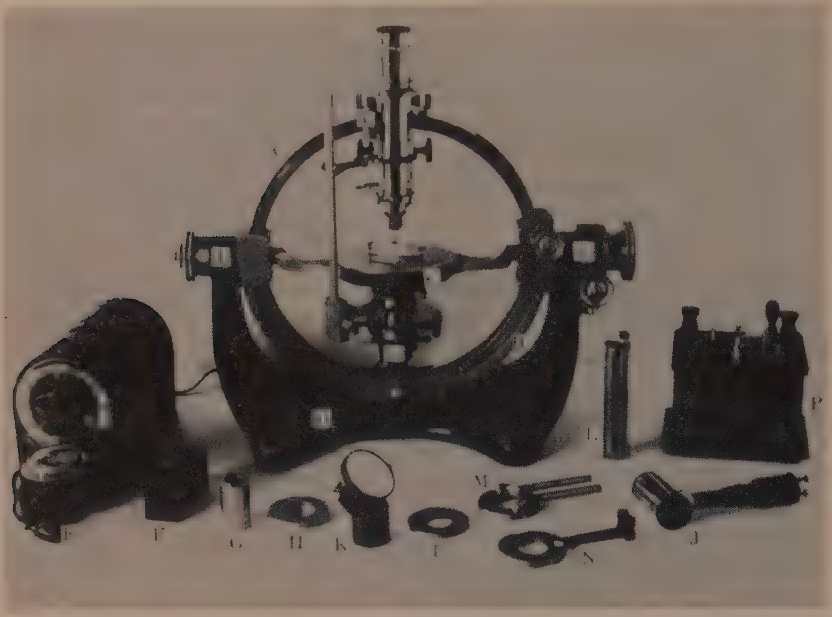

Fig. 1. Front view of the instrument and its accessories. A, Main ring. B, Semi-circle. C, Objective stage. D, Supporting base. E, Resistance coil for illuminator. F, Filters. G, Condenser for monochromator. H, Objective stage attachment for goniometer. I, Objective stage attachment for ordinary observation. J, Autocollimator ocular. K, Mirror for monochromator. L, Attachment to mount ordinary tube, A.M., C.M., Leitz microscope. M, Water cell for stage to be connected in series with the refractometer, and to be used for controlling the temperature of the immersion liquid. N, Electric heating ring for stage, to give controlled temperature to the immersion liquid. P, Variable resistance for electric heating ring.

MANIPULATION OF THE INSTRUMENT

The manipulation of this instrument is rather simple compared with that of ordinary universal stage.[3] The tube is movable in two different directions. One movement is brought about by rotating the ring A, in the semi-circle B, and the other movement by rotating the semi-circle B (with the ring A), about the horizontal axis d_1d_2. The tube may be brought to any desired position by the proper combination of the two sets of movements. The first of the two corresponds to the movement along the great circle, and the second to that along the small circle in Wulff's stereographic net.

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[3] Berek, M., *Mikroskopische Mineralbestimmung mit Hilfe der Universaldrehtischmethoden. Berlin*, **1924**.

Reinhard, M., *Universal Drehtischmethoden*, etc., *Besel*, **1931**.

Furthermore the stage can be tilted by rotating it about the horizontal axis d_1d_2. This movement, though not needed for the purpose for which the instrument was primarily devised, may be useful in certain cases.

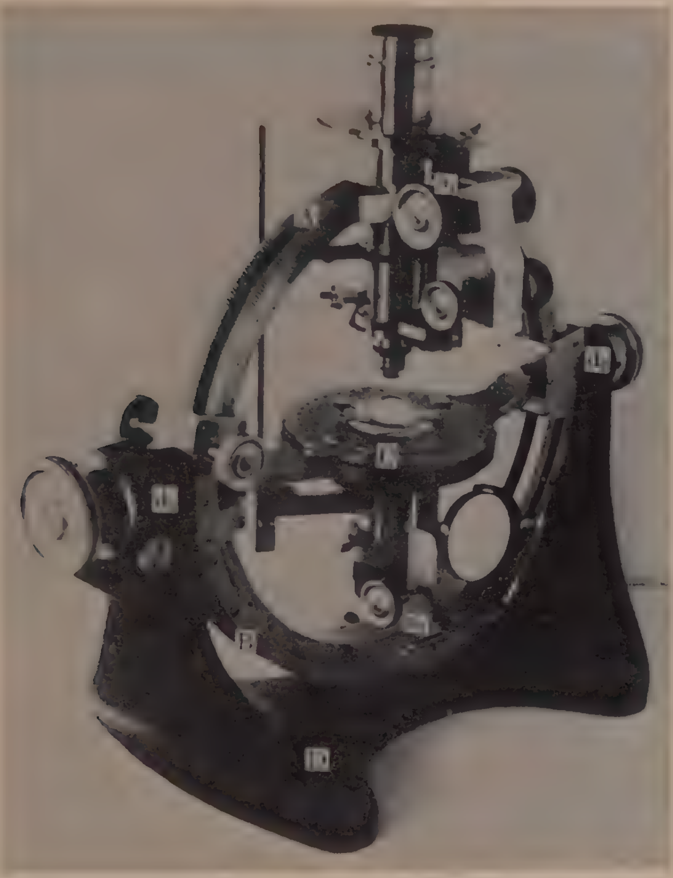

FIG. 2. Diagonal view of the instrument.

USE OF THE INSTRUMENT

While the present device is primarily for observing mineral grains immersed in a liquid, it may also be used for several other purposes.

In determining the principal refractive indices of biaxial crystals by the dispersion method, the tube is to be oriented so that its axis is parallel to one of the optical elasticity axes X, Y, or Z of the crystal. To bring the tube to the proper position, it is convenient to use the lamp, enclosed in the cylindrical case, below the stage. Then the case is replaced by the reflecting mirror which reflects light from a monochromator to the object. To determine the indices of a mineral when very few crystal grains are available, the double-variation method[4] is preferred, and furthermore the use of standard glass powders[5] may also be found very advantageous.

The instrument may be used likewise as an optic axial angle goniometer. Then objective 2, U. M. 3 or 5 (Leitz) and the Bertrand lens are used.

Also when it is used as a goniometer, an autocollimator ocular is to be attached. With this apparatus the measurement of the interfacial angles is not as accurate, and does not cover such a wide range as that of a goniometer, but this is not the main function of this apparatus. In some cases, however, such as with electrolytically deposited crystals on a plate, this apparatus may serve for rough measurements.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the assistance of the Nippon Gakuzutu Sinko Kwai (Foundation for the Promotion of Scientific and Industrial Research of Japan), for the necessary funds for constructing this instrument. Thanks are due also to Professor S. Tsuboi of the Imperial University of Tokyo, for the critical reading of this paper, and to Dr. T. Ito for his numerous suggestions. The writer also wishes to exexpress his appreciation to Mr. K. Katsura and Mr. M. Serizawa for their skill in constructing the instrument.

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[4] Emmons, R. C., *Am. Mineral.*, vol. **13,** p. 504, 1928; vol. **14,** p. 441, 1929.

[5] Sueno, T., *Am. Mineral.*, vol. **18,** p. 421, 1933.

CRYSTALLOGRAPHY OF CAESIUM MOLYBDO-TELLURATES

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AND

J. MÉLON, *Université de Liège.*

SUMMARY

Caesium molybdo-tellurate crystals are of two types: (1) equant, biaxial positive, (2) tabular, biaxial negative. Both types are triclinic, apparently holohedral.

The positive salt has the following axial elements: $a:b:c=0.9498:1:0.6059$, $\alpha=96°41'$, $\beta=102°1'$, $\gamma=101°31'$. Variable habit. Refractive indices: $n_\alpha=1.709$, $n_\beta=1.716$, $n_\gamma=1.797$. $2V=34°$. $r<v$, weak.

The negative salt has the axial elements: $a:b:c=0.9365:1:0.7989$, $\alpha=93°45'$, $\beta=94°8'$, $\gamma=88°21'$. Constant habit, tabular on $\{1\bar{1}0\}$. Refractive indices: $n_\alpha=1.669$, $n_\beta=1.734$, $n_\gamma=1.738$. $2V=30°$. $r>v$, strong.

The two types of crystals show a tendency towards homeomorphism.

The Barker classification angles are given.

INTRODUCTION

The present paper is part of the crystallographic study of a series of alkaline molybdo-tellurates.[1] The chemical study of these compounds is being carried on by Professors V. M. Meloche (Wisconsin) and S. R. Wood (Oklahoma Agricultural and Mechanical College). Their results will appear in the *Journal of the American Chemical Society.*

Our thanks are due to Dr. Wood, who prepared the crystals necessary for this investigation. The batch of crystals that he sent us were recrystallized from their aqueous solution and we found that two distinct crystal species were thus obtained. Both belong to the triclinic system but they differ in optical character and crystal habit. One type is biaxial positive, with rather equant crystals; the other is biaxial negative, with crystals showing a thin tabular habit. In our preparations crystals of the first type largely predominate.

FIRST TYPE OF CRYSTALS: EQUANT, BIAXIAL POSITIVE

General

This first type of crystals separates fairly easily from an aqueous solution, along with crystals of the second type.

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[1] Previous papers: Haüy-Bravais lattice and other crystallographic data for sodium molybdo-tellurate: *Am. Mineral.*, vol. **18**, pp. 227–47, 1933. Angles paramétriques de Barker dans une série cristalline homéomorphe: *Annales Soc. géol. Belgique*, vol. 57, B 39–52, 1933. Ammonium and potassium molybdo-tellurates, two homeomorphous orthorhombic substances: *Proc. Nat. Acad. Sci.*, vol. **20**, pp. 327–35, 1934. Crystallography of lithium molybdo-tellurate: *Am. Mineral.*, vol. **21**, pp. 125–27, 1936. Crystallography of ammonium molybdo-ditellurate: *Am. Mineral.*, vol. **21**, pp. 250–57, 1936.

The crystals are small, averaging 1 to 2 millimeters in their greatest dimension. They are colorless, translucent to transparent, usually well developed, with fairly plane faces and splendent vitreous to adamantine luster. No cleavage, parting, or twinning was observed. The crystals are brittle, with uneven fracture.

Form

The crystal system is triclinic, the class apparently holohedral (pinacoidal) $C_i=\bar{1}$.

Axial elements: $\breve{a}:\bar{b}:\overset{|}{c}=0.9498:1:0.6059$, $\alpha=96°41'$, $\beta=102°1'$, $\gamma=101°31'$; $A(010:001)=80°30'$, $B(001:100)76°14'$, $C(100:010)=76°40'$.

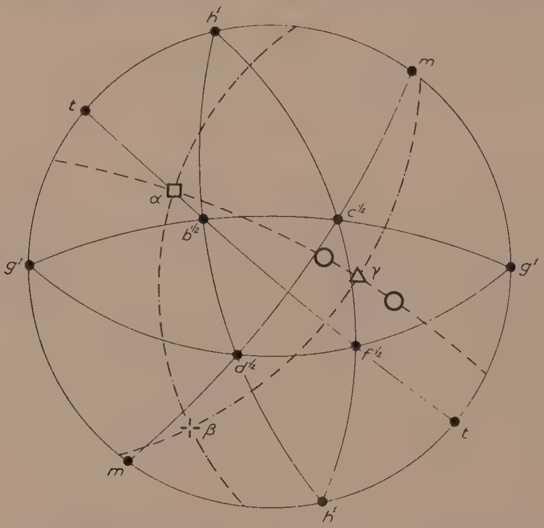

FIG. 1. Stereographic projection of the first type of crystals (biaxial positive).

Eight crystal forms[2] have been observed: $m\{1\bar{1}0\}$, $t\{110\}$, $b^{1/2}\{\bar{1}\bar{1}1\}$, $c^{1/2}\{\bar{1}11\}$, $g^1\{010\}$, $f^{1/2}\{111\}$, $d^{1/2}\{1\bar{1}1\}$, and $h^1\{100\}$. Of these the first six are always present, $d^{1/2}$ is common, h^1 is rather rare. On many crystals the two parallel faces of the same form are unequally developed (for instance: $c^{1/2}$, t, g^1); on some, one of the two is missing altogether (forms $d^{1/2}$ and h^1, especially the latter). The form g^1 shows faint striations parallel to the vertical edge [001].

Three form combinations have been encountered: (1) the first six forms alone; (2) the same with $d^{1/2}$; (3) the same with $d^{1/2}$ and h^1.

A stereographic projection is given in Fig. 1.

[2] The Lévy form-notation is used in conjunction with the Miller symbols.

Habit

The crystal habit is very variable, hence the insuperable difficulty to list the forms according to decreasing importance. In a general way, the crystals are always more or less equidimensional, somewhat flattened or elongated in different directions. A few crystals are briefly described in order to illustrate the variability of the habit.

(1) Slightly flattened on $m\{110\}$, somewhat elongated along the edge $mt[001]$. Decreasing importance[3] of faces: $\bar{1}10\cdot(1\bar{1}0\cdot110)\cdot1\bar{1}\bar{1}\cdot(11\bar{1}\cdot\bar{1}\bar{1}1\cdot0\bar{1}0\cdot\bar{1}\bar{1}0)\cdot(111\cdot\bar{1}\bar{1}\bar{1}\cdot\bar{1}11)\cdot100\cdot010\cdot\bar{1}1\bar{1}\cdot1\bar{1}1$. Missing: $\bar{1}00$. The face $m(\bar{1}10)$ is hopper-shaped.

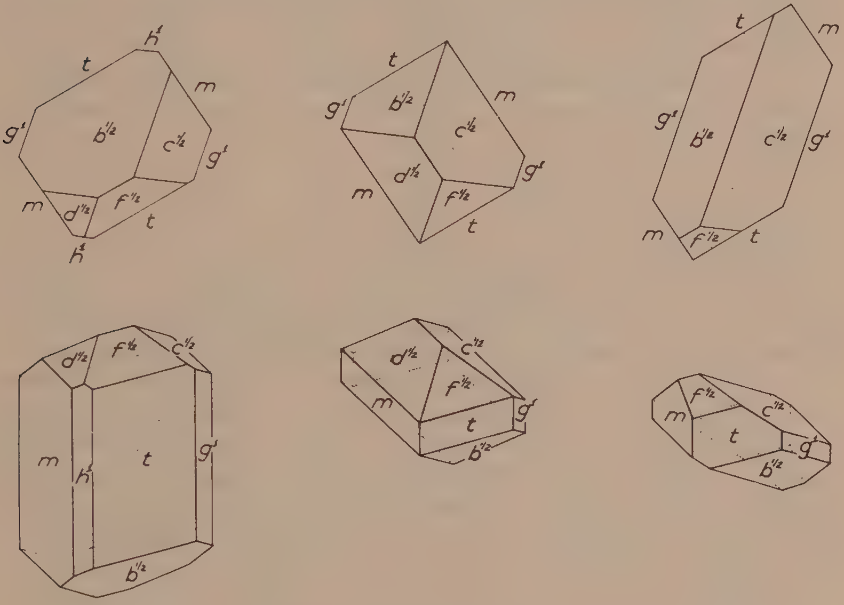

FIG. 2. Some of the habits observed on crystals of the first type (biaxial positive). Orthographic projection, 20° rotation, 20° tilt.

(2) Thick tabular on $c^{1/2}\{\bar{1}11\}$, elongated parallel to the edge $g^1c^{1/2}$ [101]. Decreasing importance of faces: $(\bar{1}11\cdot1\bar{1}\bar{1})\cdot(\bar{1}\bar{1}1\cdot11\bar{1})\cdot(110\cdot\bar{1}\bar{1}0)\cdot\bar{1}10\cdot(1\bar{1}0\cdot0\bar{1}0\cdot010)\cdot\bar{1}\bar{1}\bar{1}\cdot111$. The face $c^{1/2}$ $(1\bar{1}\bar{1})$ is hopper-shaped.

(3) Very slightly flattened on $g^1\{010\}$, somewhat elongated parallel to the edge $mt[001]$. Decreasing importance of faces: $010\cdot1\bar{1}\bar{1}\cdot1\bar{1}0\cdot\bar{1}\bar{1}1\cdot0\bar{1}0\cdot11\bar{1}\cdot\bar{1}10\cdot\bar{1}11\cdot\bar{1}\bar{1}0\cdot110\cdot(100\cdot\bar{1}00\cdot1\bar{1}1\cdot\bar{1}\bar{1}\bar{1}\cdot111)$. Missing, $\bar{1}1\bar{1}$.

(4) Very slightly flattened on $t\{110\}$. Decreasing importance of faces:

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[3] Faces that look equally developed are shown in parentheses.

$\bar{1}\bar{1}0 \cdot 110 \cdot 1\bar{1}0 \cdot 11\bar{1} \cdot \bar{1}\bar{1}1 \cdot 010 \cdot 1\bar{1}\bar{1} \cdot \bar{1}11 \cdot \bar{1}10 \cdot 0\bar{1}0 \cdot \bar{1}1\bar{1} \cdot 1\bar{1}1 \cdot \bar{1}\bar{1}\bar{1} \cdot 111 \cdot 100$. Missing: $\bar{1}00$. The face $t(\bar{1}\bar{1}0)$ is hopper-shaped.

(5) "Octahedral" habit. Decreasing importance of faces: $(\bar{1}1\bar{1} \cdot 1\bar{1}1 \cdot 1\bar{1}\bar{1} \cdot \bar{1}11) \cdot (11\bar{1} \cdot \bar{1}\bar{1}1 \cdot \bar{1}\bar{1}\bar{1} \cdot 111) \cdot (1\bar{1}0 \cdot \bar{1}10) \cdot (\bar{1}\bar{1}0 \cdot 110) \cdot (0\bar{1}0 \cdot 010)$.

Some of the habits are illustrated by the crystal drawings in Fig. 2.

It should be pointed out that whenever a face is hopper-shaped, the crystal is slightly flattened on that face. The skeletal development may affect any face on which the crystal happens to lie at the bottom of the beaker during growth. It may then be safely inferred that the observed variations of the habit are accidental, in the sense that they are due to the conditions of crystallization. The mere fact that a growing crystal happens to lie on one rather than another face may apparently be sufficient cause to alter the habit that the Law of Bravais would normally require.

Measurements and calculations

Five crystals have been measured on the non-modified one-circle Wollaston goniometer. Although the signal images reflected by the faces were, on the whole, rather distinct, the series of readings are quite widespread (about 40′, as much as 1° in a few cases) and, at best, mediocre.

Only one 4-plane zone is present (g^1mh^1t). The interfacial angles in that zone are among the best obtained. We have followed the method advocated by T. V. Barker[4] for the mutual adjustment of fundamental angles. The angles g^1t (010:110) and g^1m ($010:1\bar{1}0$) have been adjusted by means of the angle g^1h^1 (010:100). These two adjusted values, together with the other three best interfacial angles, were adopted as fundamental.

The calculations were made by the usual methods of spherical trigonometry. The setting adopted for the description of the crystals was arrived at by applying the rules of the Barker method.[5] Since no one setting seemed to be particularly indicated from the morphological point of view, we thought it best to adopt the setting that fits the Barker determinative scheme.

A comparison of measured and calculated angles will be found in Table 1. For each series of measurements, the probable error is given so that the reliability of the mean value can be estimated. The accuracy of the axial elements is discussed later.

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[4] Barker, T. V., *Graphical and tabular methods in crystallography*, p. 100, London, Thomas Murby and Co., 1922.

[5] Barker, T. V., *Systematic crystallography*, London, Thomas Murby and Co., 1930.

TABLE 1. EQUANT, BIAXIAL POSITIVE CRYSTALS
COMPARISON BETWEEN MEASURED AND CALCULATED ANGLES
$\breve{a}:\bar{b}:\overset{|}{c}=0.9498:1:0.6059$, $\alpha=96°41'$, $\beta=102°1'$, $\gamma=101°31'$. (Axial elements derived from five crystals)

Number of readings	Probable error	Lévy	Angle Miller	Barker	Measured (mean)	Computed
21	13.8′	g^1t	010:110	bm	39°58′	**39°51′
16	10.9′	g^1m	$010:1\bar{1}0$	bM	126°11′	**125°55
7	8.4′	g^1h^1	010:100	ba	†76°47′	76°40′
18	9.7′	$g^1c^{\frac{1}{2}}$	$010:\bar{1}11$	bp	*59°30′	—
17	11.4′	$g^1b^{\frac{1}{2}}$	$010:\bar{1}\bar{1}1$	bP	*119°12′	—
10	18.2′	$m\ c^{\frac{1}{2}}$	$1\bar{1}0:\bar{1}11$	Mp	126° 1′	125°20′
8	23.7′	$m\ d^{\frac{1}{2}}$	$1\bar{1}0:1\bar{1}1$	MO	49°55′	49°41′
18	18.4′	$t\ b^{\frac{1}{2}}$	$110:\bar{1}\bar{1}1$	mP	*126°50′	—
12	25.6′	$t\ f^{\frac{1}{2}}$	110:111	mo	38° 7′	37°55
4	15.9′	$t\ c^{\frac{1}{2}}$	$110:\bar{1}11$	mp	80°20′	80°21′
1	—	$t\ d^{\frac{1}{2}}$	$110:1\bar{1}1$	mO	76°–77°	76°13′
1	—	$b^{\frac{1}{2}}d^{\frac{1}{2}}$	$\bar{1}\bar{1}1:1\bar{1}1$	PO	61°47′	61°43′

N.B.—The five values marked with either one or two asterisks (* or **) are chosen as fundamental angles. The two values marked with two asterisks (**) are values adjusted by means of the measured angle marked with a dagger (†).

Barker classification angles

The parametral angles necessary in order to identify this substance according to the Barker determinative method have been computed. The Barker form letters are as follows: c(001), r(101), a(100), m(110), b(010), q(011), o(111).

The different combinations of forms observed lead to several solutions.

(1) Two combinations lead to the same setting and orientation.

Transformation: none.

Forms: $1\bar{1}0\cdot110\cdot\bar{1}\bar{1}1\cdot\bar{1}11\cdot010\cdot111\cdot1\bar{1}1$; 100.

Angles:

cr = 28°33′, ra = 47°41′, **am = 36°49′**, mb = 39°51′, bq = 52°2′, qc = 28°28′.

Remarks: The order of decreasing importance is difficult to ascertain for the first six forms. The forms that precede a semi-colon (or the final period) in the above list are observed combinations.

(2) The combinations of the first six forms leads to one and the same setting with two possible different orientations. This is due to the fact that two angles, which must be compared in order to find the correct orientation, are within 1° of each other (37°55′ and 37°7′). In such a case,

they are to be considered equal, and two entries are consequently worked out.[6] The latter are as follows:

(2*a*) Transformation: Old to new $=\bar{1}\bar{1}0/\bar{1}10/00\bar{2}$.
New to old $=\bar{1}\bar{1}0/\bar{1}10/00\bar{1}$.

Forms: $\dfrac{\text{Old: } 1\bar{1}0\cdot 110\cdot \bar{1}\bar{1}1\cdot \bar{1}11\cdot 010\cdot 111.}{\text{New: } 0\bar{1}0\cdot \bar{1}00\cdot 10\bar{1}\cdot 01\bar{1}\cdot \bar{1}10\cdot \bar{1}0\bar{1}.}$

Angles:
cr = 37°7′, ra = 37°55′, **am = 36°49′**, mb = 49°15′, bq = 49°41′, qc = 36°19′.

(2*b*) Transformation: Old to new $=002/1\bar{1}0/110$.
New to old $=011/0\bar{1}1/100$.

Forms: $\dfrac{\text{Old: } 1\bar{1}0\cdot 110\cdot \bar{1}\bar{1}1\cdot \bar{1}11\cdot 010\cdot 111.}{\text{New: } 010\cdot 001\cdot 10\bar{1}\cdot 1\bar{1}0\cdot 0\bar{1}1\cdot 101.}$

† Angles:
cr = 37°55′, ra = 37°7′, **am = 36°19′**, mb = 49°41′, bq = 49°15′, qc = 36°49′.

Optical properties

The refractive indices, obtained by the immersion method, are: $n_\alpha = 1.709 \pm 0.003$, $n_\beta = 1.716 \pm 0.002$, $n_\gamma = 1.797 \pm 0.005$. The crystals are biaxial positive. The optic angle $2V = 34°$ (measured on universal stage); the value of $2V$ calculated from the indices is also 34°. Dispersion: $r < v$, weak.

The optical orientation is difficult to determine. The three axes of the index ellipsoid can be located by measurements on the Fedorov universal stage, but even the smallest crystals that can be handled give too high a retardation to ascertain which is which. Many crystals obtained by recrystallization on a glass slip lie on a face of the form $b^{1/2}\{\bar{1}\bar{1}1\}$, as can be shown by measuring the plane angles between edges. Such preparations are thin enough to permit recognition of the three axes of the indicatrix on the universal stage.

The optic angle $2V$ is measured on fragments of crystals. The elements of the index ellipsoid are plotted on a stereographic projection and their coordinates (longitudes ϕ and colatitudes ρ) are thus determined graphically. Longitudes are counted clockwise from the plane normal to $g^1(010)$, taken as zero meridian. The results are as follows:

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[6] In accordance with the general rule proposed by Mr. R. C. Spiller (Oxford University) for the compilation of the Barker determinative index (unpublished memorandum, private communication). It seems desirable that, in the Index, some typographical sign (a dagger, e.g.) precede the list of angles of every additional entry (such as 2*b*), in which CR is larger than RA, contrary to the usual convention. This would attract the attention of the chemist who is using the Index and would indicate to him that he is dealing with a "freak" entry, not a misprint as he might well think on noticing that CR is greater than RA!

	ϕ	ρ
α	218½°	54°
β	116°	74°
γ	6°	41°
O.A. 1	15½°	56½°
O.A. 2	350½°	26°

Remarks on the accuracy of the axial elements

The poor agreement obtained between measured and calculated angles raises the question of the accuracy of the axial elements.

In our calculations we have used as fundamental angles the weighted average of all the readings obtained from five different crystals. Should these crystals belong to an isomorphous series and have slight differences in composition, it is obvious that better agreement would be reached between measured and calculated angles if each crystal were computed separately. We have, therefore, repeated the calculations for the crystal that seemed to yield the most satisfactory measurements.

The results are as follows:

Forms present: $m\{1\bar{1}0\}$, $t\{110\}$, $b^{1/2}\{\bar{1}\bar{1}1\}$, $c^{1/2}\{\bar{1}11\}$, $f^{1/2}\{111\}$, $d^{1/2}\{1\bar{1}1\}$, $g^1\{010\}$, $h^1\{100\}$.
Axial elements: $\breve{a}:\bar{b}:\acute{c}=0.9523:1:0.6092$, $\alpha=96°44'$, $\beta=101°56'$, $\gamma=101°9'$.
Comparison between measured and calculated angles will be found in Table 2.

The agreement is not much better than with the elements calculated from 5 crystals, as a comparison of Tables 1 and 2 will show. It does not seem likely that we are dealing here with crystals of an isomorphous series. The unsatisfactory results obtained can safely be ascribed to the imperfection of the crystals measured.

From the two sets of axial elements calculated here, it can be seen that not more than two decimal places are reliable in the axial ratios (0.95:1:0.61) and that the interaxial angles may be in error by almost half a degree.

The tedious recalculation of the axial elements from fundamental angles obtained from one crystal only, at any rate, has had the merit of emphasizing this point.

TABLE 2. EQUANT, BIAXIAL POSITIVE CRYSTALS
COMPARISON BETWEEN MEASURED AND CALCULATED ANGLES

$\breve{a}:\bar{b}:\acute{c}=0.9523:1:6092$, $\alpha=96°44'$, $\beta=101°56'$, $\gamma=101°9'$. (Axial elements derived from one crystal only)

Number of readings	Angle		Measured (mean)	Calculated
	Lévy	Miller		
4	g^1t	$010:110$	*39°59′	—
4	g^1m	$010:1\bar{1}0$	*126°14′	—
2	g^1h^1	$010:100$	76°58′	77°3′
4	$g^1c^{\frac{1}{2}}$	$010:\bar{1}11$	*59°19′	—
4	$g^1b^{\frac{1}{2}}$	$010:\bar{1}\bar{1}1$	*119° 9′	—
4	$m\,c^{\frac{1}{2}}$	$1\bar{1}0:\bar{1}11$	126° 7′	125°37′
2	$m\,d^{\frac{1}{2}}$	$1\bar{1}0:1\bar{1}1$	49°51′	49°34′
4	$t\,b^{\frac{1}{2}}$	$110:\bar{1}\bar{1}1$	*126°53′	—
3	$t\,f^{\frac{1}{2}}$	$110:111$	38°22′	37°58′
2	$c^{\frac{1}{2}}d^{\frac{1}{2}}$	$\bar{1}11:1\bar{1}1$	76°16′	76° 3′
2	$b^{\frac{1}{2}}f^{\frac{1}{2}}$	$\bar{1}\bar{1}1:111$	88°25′	88°55′

N.B.—The angles marked with an asterisk (*) are chosen as fundamental.

SECOND TYPE OF CRYSTALS: TABULAR, BIAXIAL NEGATIVE

General

The second type of crystals separates from an aqueous solution along with crystals of the first type, described in the foregoing sections. We have obtained no batch consisting of only one type of crystals.

The crystals of the second type are slightly larger than those of the first type; their greatest dimension averages 3 millimeters, ranging from 0.5 to 5 millimeters. They are clear, colorless, transparent, usually well developed with fairly plane faces showing good vitreous luster. No cleavage, parting, or twinning. The crystals are fragile, their fracture is irregular.

Form

The crystal system is triclinic; the class, apparently holohedral (pinacoidal) $C_i=\bar{1}$.

Axial elements: $\breve{a}:\bar{b}:\acute{c}=0.9365:1:0.7989$, $\alpha=93°45'$, $\beta=94°8'$, $\gamma=88°21'$; $A=86°22'$, $B=85°58'$, $C=91°23'$.

Seven crystal forms have been observed: $m\{1\bar{1}0\}$, $a^1\{\bar{1}01\}$, $h^1\{100\}$, $i^1\{011\}$, $t\{110\}$, $e^1\{0\bar{1}1\}$, and ${}^2h\{3\bar{1}0\}$. Of these the forms m, a^1, h^1, and i^1 are always present; t and e^1 are also always observed, but one of the two faces of the form is missing on several of the crystals examined; the form ^2h has been detected (with one face missing) on one crystal only. Two form combinations can thus be recorded: m a^1 h^1 i^1 t e^1, with or without ^2h. The form m is striated parallel with the edge mt [001].

A stereographic projection is given in Fig. 3.

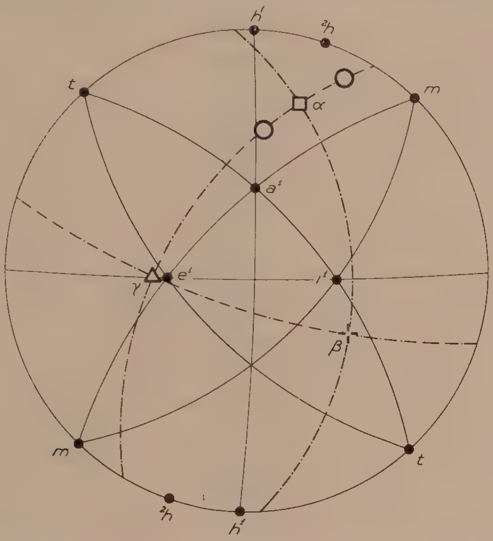

Fig. 3. Sterographic projection of the second type of crystals (biaxial negative).

The Federov symbol for crystals of the second type was kindly determined for us by Mr. W. J. van Weerden (Rijks-Universiteit te Groningen, Holland). It is as follows:

$$\begin{matrix} 4\ o;\ +5\tfrac{1}{2}\ 4 \\ 50\quad 0 \\ -\tfrac{1}{2} \end{matrix}$$

The following transformation enables one to pass from the setting adopted in this paper to the Fedorov setting:

$$\bar{1}00/0\bar{1}0/001.$$

The face symbols in the Fedorov setting are thus obtained by changing the sign of the first two indices in our face symbols.

Habit

The crystal habit is very constant, thin tabular on $m\{1\bar{1}0\}$. The plates are somewhat more elongated along the edge $ma^1[111]$ than along the edge $mt[001]$. The order of forms, listed according to decreasing size is as follows: $m\ a^1\ (h^1 i^1)\ t\ e^1;\ {}^2h$. The form m is much larger than all others; the forms h^1, i^1, and perhaps t, look equally important; e^1 is a narrow form; ${}^2h$ is seen as a rare line-face.

One crystal drawing suffices to illustrate the habit and is shown in Fig. 4.

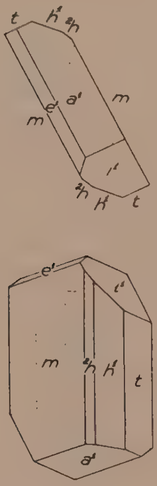

FIG. 4. The constant habit of crystals of the second type (biaxial negative). Orthographic projection, 20° rotation, 20° tilt.

The largest form m generally has one face hopper-shaped as the crystal tends to lie on it during growth.

Measurements and calculations

Half a dozen crystals have been measured on the one-circle goniometer. The readings were, on the whole, unsatisfactory; the reflected signals being often multiple or faint. The series of readings were even more widespread than in the first type of crystals (over one degree). The mean error for the best series was 2.8′ (angle $a^1 i^1$); three series of readings gave a mean error of 7′ or 7.5′ (mi^1, mt, h^1t). The probable errors are given in Table 2; they range from 10′ to half a degree.

The Barker setting obtained from the most common form combination ($m\ a^1\ h^1\ i^1\ t\ e^1$) has been adopted for the purpose of crystal description.

Measured and calculated angles show poor agreement (see Table 3).

TABLE 3. TABULAR, BIAXIAL NEGATIVE CRYSTALS
COMPARISON BETWEEN MEASURED AND CALCULATED ANGLES
$\check{a}:\bar{b}:\dot{c}=0.9365:1:0.7989$, $\alpha=93°45'$, $\beta=94°8'$, $\gamma=88°21'$.

Number of readings	Probable error	Angle			Measured (mean)	Computed
		Lévy	Miller	Barker		
14	12.4′	$m\ e^1$	$1\bar{1}0:0\bar{1}1$	MQ	*63° 7′	—
17	29.8′	$m\ a^1$	$1\bar{1}0:\bar{1}01$	MR	*119°19′	—
11	16.0′	$m\ t$	$1\bar{1}0:110$	Mm	*86°13′	—
17	25.7′	$m\ h^1$	$1\bar{1}0:100$	Ma	41°38′	42°27′
10	22.5′	$h^1\ t$	$100:110$	am	44°36′	43°45′
2	—	$m\ {}^2h$	$\bar{1}10:\bar{3}10$	—	25°31′	25°15′
12	27.1′	$m\ i^1$	$\bar{1}10:011$	M′q	*65°36′	—
10	10.0′	a^1i^1	$\bar{1}01:011$	Rq	*52°54′	—
2	—	h^1a^1	$\bar{1}00:\bar{1}01$	a′R	50°28′	51°56′
3	—	$t\ a^1$	$\bar{1}\bar{1}0:\bar{1}01$	m′R	65° 9′	65°48′
1	—	h^1i^1	$100:011$	aq	88°18′	87°47′

N.B.—The five angles marked (*) are chosen as fundamental.

Barker classification angles

Two entries in the Barker determinative Index are necessary, one for each form combination.

(1) Transformation: none.
Forms: $1\bar{1}0\cdot\bar{1}01\cdot100\cdot011\cdot100\cdot0\bar{1}1$.
Angles:
cr = 38°43′, ra = 47°15′, **am = 43°45′**, mb = 47°38′, bq = 49°14′, qc = 37°8′.

(2) Transformation: Old to new $=0\bar{2}0/00\bar{2}/111$.
New to old $=112/\bar{1}00/0\bar{1}0$.

$$\text{Forms: } \frac{\text{Old: } 1\bar{1}0\cdot\bar{1}01\cdot100\cdot011\cdot110\cdot0\bar{1}1;\ 3\bar{1}0.}{\text{New: } 100\cdot0\bar{1}0\cdot001\cdot\bar{1}\bar{1}1\cdot\bar{1}01\cdot1\bar{1}0;\ 101.}$$

Angles:
cr = 17°12′, ra = 25°15′, **am = 31°32′**, mb = 29°9′, bq = 30°3′, qc = 21°53′.
Remark: The forms are listed in the order of decreasing importance.

Optical properties

The refractive indices, obtained by the immersion method, are: $n_\alpha=1.669\pm0.001$, $n_\beta=1.734\pm0.002$, $n_\gamma=1.738\pm0.001$. The crystals are biaxial negative. The optic angle, measured on the Fedorov stage, is 2V = 30°; calculated from the indices, the value of 2V is 27°. Dispersion: $r>v$, strong.

Optical orientation.—Measurements on the Fedorov universal stage enabled us to locate the position of γ, β, and both optic axes. We give the orientation by means of longitudes and colatitudes, measured from the stereographic projection (Fig. 3). The zero meridian is taken normal to the dominant face $m(\bar{1}10)$. Longitudes are measured clockwise.

	ϕ	ρ
α	333½°	72°
β	77½°	52°
γ	222½°	42½°
O.A.1	323°	61°
O.A.2	342½°	84°

Since the crystal habit is very constant, thin tabular on $m\{1\bar{1}0\}$, the optical appearance of this face is a good determinative character of the species. An excellent interference figure is obtained in convergent light; one of the optic axes emerges on the edge of the field, the face $m(1\bar{1}0)$ being oblique to an optic axis. The angle between the normal to *m* and the optic axis is *ca.* 35° (estimated) in air; hence a true value of 19°. The same angle, read on the stereographic projection, is equal to 18½°; the check is thus quite close. The isogyre of the interference figure is fringed with red on the convex side, with blue on the concave, showing the strong dispersion of the optic axes. Small crystals, mounted with wax on match sticks, can be held in various orientations under the microscope; other types of triclinic dispersion can thus be obtained, all of which are devoid of symmetry.

COMPARISON AS TO HOMEOMORPHISM

The two salts show a tendency to homeomorphism as can be seen from the superposition of the two stereographic projections (Fig. 5).

This rough similarity could be emphasized by changing the crystallographic setting of one salt in order to give the same symbols to corresponding faces, for instance by means of the transformation $\bar{1}\bar{1}0/\bar{1}10/00\bar{2}$ applied to the positive salt.[7] The face symbols of the positive crystals are then changed as follows:

Old: $0\bar{1}0 \cdot \bar{1}\bar{1}0 \cdot \bar{1}00 \cdot \bar{1}10 \cdot \bar{1}\bar{1}\bar{1} \cdot \bar{1}1\bar{1} \cdot 11\bar{1} \cdot 1\bar{1}\bar{1}$.

New: $1\bar{1}0 \cdot 100 \cdot 110 \cdot 010 \cdot 101 \cdot 011 \cdot \bar{1}01 \cdot 0\bar{1}1$.

The new symbols are used in Fig. 5.

Although this crystallographic resemblance is very crude, it is worth mentioning in view of the presumed chemical similarity of the two substances.

[7] The transformation $\bar{1}\bar{1}0/\bar{1}10/00\bar{1}$, applied to the negative salt, would serve the purpose just as well.

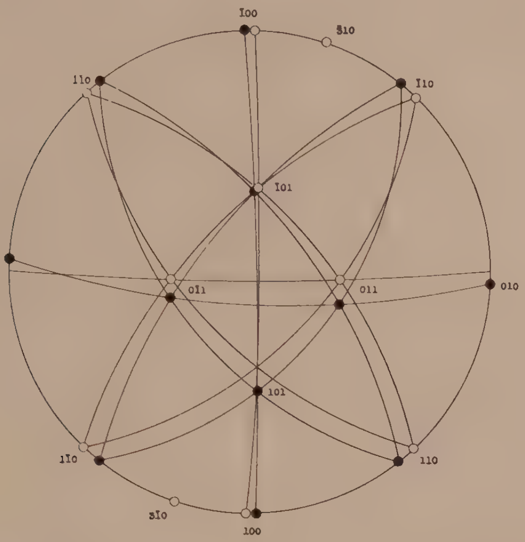

FIG. 5. Comparison as to homeomorphism. The projection of the negative salt (circles) is that of Fig. 3; the projection of the positive salt (black spots) is obtained from that of Fig. 1 by applying the transformation: Old to New = ĪĪ0/Ī10/002̄.

XENOLITHS IN THE ORGAN BATHOLITH, NEW MEXICO

KINGSLEY C. DUNHAM,
Geological Survey of Great Britain.

With a Morphological Description of Diopside Crystals

By M. A. PEACOCK, *Harvard University.*

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INTRODUCTION

The Organ Mountains lie on the east side of the Rio Grande in Southern New Mexico, east of the town of Las Cruces. During 1933–1935 they were the object of a field study, the results of which will shortly appear.[1] In the course of mapping the Tertiary batholith from which the most spectacular part of the range has been carved, several groups of large accidental xenoliths were discovered, among which the most interesting proved to be those situated near South Canyon on the east side of the mountains, 15 miles by desert road south of San Agustin Pass. The present note is concerned mainly with the geology and mineralogy of these xenoliths, which are of special interest to mineralogists because of the presence in some of them of well-crystallized green diopside, associated with the chrome-garnet uvarovite.

Dr. M. A. Peacock has kindly undertaken a morphological study of the diopside crystals, and a summary of his results is included in this paper. The writer wishes to express his gratitude to him, and also to Professors Palache and Larsen for laboratory facilities at Harvard University, where the petrographic examination of the material was carried out.

GENERAL GEOLOGY

The following is a brief outline of the geology of the Organ Mountains:

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[1] Dunham, K. C., The geology of the Organ Mountains, *N. Mex. Sch. Mines, State Bur. Mines Min. Res.*, Bull. **11**, 1936.

On the east side of the range are exposed Pre-Cambrian granites containing masses of schist, gneiss and quartzite. The granites are cut by epidiorite dikes, also of Pre-Cambrian age, which were probably intruded as diabases, but which have suffered metamorphism to oligoclase-amphibolites. Resting on the crystalline basement there is a succession of sedimentary rocks including the Bliss sandstone (Cambrian), the El Paso and Montoya formations (Ordovician), the Fusselman formation (Silurian), the Percha shale (Devonian), the Lake Valley limestone (Mississippian) and the Magdalena limestone series (Pennsylvanian). The Ordovician and Silurian rocks consist almost wholly of "formational" dolomites, while the post-Devonian calcareous rocks are calcitic limestones. Late Cretaceous or Tertiary lavas overlie an eroded surface of Pennsylvanian rocks; they include rhyolite-tuffs, rhyolites and andesites. Following the outpouring of the lavas came the intrusion of a composite batholith in which there were three major intrusive phases: (1) dark monzonite, (2) quartz monzonite, (3) quartz-bearing monzonite. The batholith visibly cuts across all earlier formations from the Pre-Cambrian rocks to the lavas. It is considered to have been emplaced by stoping, a conclusion which is supported by the presence in it of large masses of the country rock. There appears to have been a progressive concentration of volatile fluxes and hyperfusibles during the intrusive cycle, for while phase (2) was able to bring about metamorphic effects involving only limited metasomatic changes in the rocks engulfed in and adjacent to it, phase (3) gave rise to intense metasomatism in the rocks bordering on it, during which silicates and metallic sulphides and tellurides were introduced. The effects to be described in this note are related only to phase (2); a more complete account of the Tertiary metamorphism will be found in the publication mentioned above.

The South Canyon Xenoliths

Accidental inclusions. On the south side of South Canyon, xenoliths of granite, epidiorite, shale, dolomite and limestone are found enclosed in the quartz monzonite (intrusive phase 2). Their lithology, as seen in the field, is so little modified that no hesitation is felt in assigning their origin to the formations into which the batholith was intruded. The accompanying map (Fig. 1) shows the distribution and character of the xenoliths. They vary in length from about 50 feet to over 2000 feet; there is a remarkable lack of smaller accidental inclusions, though small cognate xenoliths, derived from the dark monzonite (intrusive phase 1) are found in the quartz monzonite. The former character of the sedimentary inclusions is evident from their texture and from the minerals which have been developed in them by metamorphism.

The granite inclusions on the southeast side of the ridge have suffered no alteration; evidently the minerals were stable in the thermal and chemical environment of the quartz monzonite magma. Epidiorite dikes cutting through the granite inclusions, however, have been profoundly

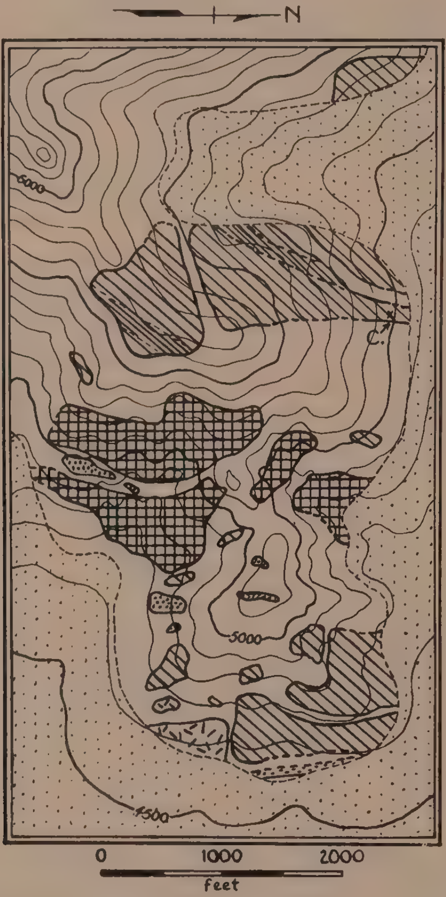

FIG. 1. Geologic Map of the ridge south of South Canyon, Organ Mountains.
Unshaded areas, quartz monzonite.
Diagonal shading, limestone xenoliths, possibly containing some magnesian beds at the east end of the ridge.
Closed-spaced diagonal shading, shale-limestone xenoliths.
Cross shading, dolomite xenoliths.
Irregular shading, Pre-Cambrian granite and epidiorite.
Heavy stipple, quartzite xenoliths.
Light stipple, alluvium.
Contour interval, 100 feet.

changed. In areas remote from the metamorphosing influence of the Tertiary batholith, the epidiorites consist of oligoclase in lath-shaped crystals which were formerly more calcic (as shown by remnants of feldspar ranging from labradorite to andesine, and by their shape), with secondary hornblende and actinolite. The metamorphism of these dikes, from diabase to epidiorite, is believed to have taken place prior to the Tertiary intrusive cycle, and to bear no relation to this cycle. After further metamorphism of the epidiorite in the xenoliths by the quartz monzonite there were developed irregular masses of andesine, $Ab_{68}An_{32}$, and streaks of colorless pyroxene with the following optical properties: Biaxial positive; $2V=60°$; $\alpha=1.680$, $\beta=1.689$, $\gamma=1.708$; maximum extinction against the (110) cleavage, 43°. In one specimen examined microscopically, pleochroic blue apatites up to 3 mm. long were noted. Clinozoisite is locally present in these rocks, and magnetite grains are abundant.

The quartzites show little alteration in the South Canyon area, but further north, in Rucca Canyon, quartzite xenoliths containing blue lazulite, andalusite, rutile and muscovite were found.

The dolomite xenoliths have been uniformly converted into brucite-marble and brucite-serpentine marble. Three stages in the metamorphism of these inclusions may be recognized. In pure dolomites, the first stage was the production of periclase, which is still fairly abundant in the large brucite marble masses south of the crest of the ridge shown in Fig. 1. It occurs in small idiomorphic crystals ($n=1.740$) which stand out in bold relief against the carbonate matrix. In siliceous dolomite beds, the magnesia and silica combined during the first stage to give rise to forsterite, which occurs in colorless crystals with the following optical properties: Biaxial, $2V=90°$, $\alpha=1.637$, $\beta=1.665$, $\gamma=1.672$; no cleavage. The El Paso formation contains siliceous streaks, possibly the remains of sea weed. Streaks identical in appearance with these are found in the xenoliths, but they consist not of silica but of forsterite, with some associated ferruginous material. The conversion of the $MgCO_3$ in the dolomite to periclase and forsterite seems to have been remarkably complete, since the carbonate matrix now consists of calcite ($\gamma=1.660$).

The second stage of metamorphism brought about the partial hydration of the periclase to brucite, which in rosette-like aggregates is now the most abundant new mineral of the xenoliths. Forsterite was partly converted into serpentine. Later than these changes, the third stage of metamorphism led to the production locally of lenticular bodies of magnesite from the brucite-serpentine marble.

The shale specimens examined exhibit only slight evidence of alteration. The clay material has apparently been converted into white mica, which occurs in bands of different grain size. There is no evidence of directional orientation of the mica.

The limestone inclusions, probably derived from the Carboniferous series, present more variety in composition than the dolomites. New minerals therefore tend to be restricted to certain beds in the xenoliths, while other beds contain only recrystallized calcite. The diopside and uvarovite occur in one such bed, in the large inclusion at the west end of the ridge shown on Fig. 1. An excavation at the point marked "C" on the map has exposed the bed, which is about 2 feet thick, and which dips 70° west and strikes N.15°E. In material from this pit, wollastonite, white mica and green diopside were found in thin sections. The diopside has grown partly in coarse white calcite, and partly in narrow open cavities; it has developed excellent crystals, which are described in the next section. Further south, apparently in the same bed, small emerald green crystals of uvarovite are abundant. This mineral has a refractive index exceeding 1.85; in thin section its green color is very noticeable, and in crossed polarized light it is found to be feebly birefringent, giving a gray interference color. One specimen shows its relation to grossularite and diopside, with which it is associated. The grossularite crystals ($n=1.731$) are about 2 mm. in diameter and are nearly free from inclusions. They have not developed crystal faces, but are surrounded by a fine-grained intergrowth of uvarovite and diopside. Veinlets of colorless apophyllite traverse this rock.

Other beds in the limestone xenoliths contain grossularite, wollastonite, diopside and tremolite.

Contamination of the intrusive rock. Specimens of the quartz monzonite taken near its contact with the dolomite xenoliths failed to show any abnormal features; the normal minerals of the rock, oligoclase, orthoclase-perthite, biotite and quartz were present in their usual proportions. It appears then, that there was no tendency for the magnesia to combine with the magma to produce new minerals. At many points near the limestone xenoliths, no change could be detected, but between the limestone and granite xenoliths at the east end of the ridge, an area of contaminated monzonite was found. Here the minerals consist of oligoclase and orthoclase-perthite, both apparently crystallized earlier than the exotic minerals. A zonal intergrowth of quartz and a birefringent garnet ($n=1.800$) followed; this intergrowth is believed to have developed at the time when quartz would normally have been crystallizing in the igneous rock. Fibrous actinolite also occurs.

Theoretical considerations. The results of the metamorphism of the xenoliths are summarized in the accompanying table:

	BEFORE METAMORPHISM	AFTER METAMORPHISM
Granite	Orthoclase Quartz Biotite	No change
Epidiorite	Hornblende Actinolite Oligoclase or Andesine Magnetite	Augite, Apatite, Andesine, Clinozoisite, Magnetite
Quartzite	Quartz Glauconite Clay material	Quartz, Lazulite, Andalusite, Rutile, White mica
Dolomite	Pure dolomite Siliceous dolomite	Periclase, Brucite (Magnesite), Forsterite, Serpentine, Periclase, Brucite (Magnesite)
Limestone	Calcite, Silica	Wollastonite, Grossularite, Diopside, Uvarovite, Apophyllite
Shale	Clay material	White mica

This table shows that the constituents necessary for making most of these minerals are already available in the rocks undergoing metamorphism. In a general way the changes may be classed as due to "thermal metamorphism" in the sense of Harker;[2] however, the evidence indicates clearly that water has played its part in the process, and while it is not necessary to postulate wholesale introduction of silica, there may well have been some migration of this substance. This process, with the elimination of carbon dioxide and the addition of water, has undoubtedly brought about substantial changes in composition, and it is clearly impossible to draw a rigid distinction here between thermal metamorphism and metasomatism.

In the case of the chromium, there can be little doubt that it was introduced from the magma; uvarovite must be classed as metasomatic. As far as the writer is aware, the only other example of chromium minerals developed from solutions arising from a granitic (rather than a gabbroic) magma, is that recently described by Eskola from Outokumpu, Finland.[3] The occurrence lends confirmation to Sampson's view that chromium may appear as a constituent of hydrothermal solutions.[4]

[2] Harker, A., *Metamorphism,* London, **1932,** pp. 7, 14–18.

[3] Eskola, P., On the Chrome minerals of Outokumpu: *Bull. Comm. Géol. Finlande,* **103,** pp. 26–44, 1933.

[4] Sampson, E., Varieties of chromite deposits: *Econ. Geol.,* vol. **26,** pp. 833–839, 1931.

At the level in the earth's crust at which the magma consolidated, probably a shallow one, there was no quantitatively important assimilation of the limestone and other included rocks. The local development of garnet in the quartz monzonite is evidence of only feeble contamination. The evidence here described provides no solution to the riddle of the fate of the vast quantity of sedimentary and igneous material which was removed by stoping to make room for the batholith.

GREEN DIOPSIDE

Morphology. The diopside from the limestone inclusions occurs in drusy crusts of close-set olive-green crystals 1–3 mm. in diameter and in single yellow-green crystals, up to 12 mm. across, emplanted on the calcite matrix. The smallest crystals are suitable for exact measurement on the goniometer. The following forms were determined on three crystals which are representative of the occurrence: *c*(001), *b*(010), *a*(100), *m*(110), *z*(021), *p*($\bar{1}$01), *u*(111), *s*($\bar{1}$11), *o*($\bar{2}$21), λ($\bar{3}$31), *I*($\bar{2}$11), γ($\bar{1}$51). The following two-circle angles measured on one twin crystal are in very close agreement with Goldschmidt's[5] calculated angles for diopside:

Forms	No. of faces	Measured		Calculated	
		φ	ρ	φ	ρ
b 010	2	0°00′	90°00′	0°00′	90°00′
a 100	2	89 59	90 00	90 00	90 00
m 110	4	43 34	90 00	43 33	90 00
z 021	4	13 32	50 34	13 32½	50 29
s $\bar{1}$11	2	−25 14	33 05½	−25 07½	33 04
o $\bar{2}$21	1	−35 07	55 21	−35 22	55 19½
γ $\bar{1}$51	2	−5 18	71 25	− 5 21½	71 20

The twelve forms observed are all among the well-known forms of monoclinic pyroxene and, except for *I*($\bar{2}$11), they are among the commoner forms of this form-rich species. Figures 2 and 3 illustrate typical crystals which closely approach the ideal symmetry of the drawings. Single crystals (Fig. 2) are few; most of the crystals are contact twins (Fig. 3) after the common pyroxene law: twinning by reflection in (100) with composition on this plane. The crystals do not vary greatly in habit. In the prism zone *m* is large, *a* and *b* narrower; on the terminations *c z u s o* γ are commonly present; *p I* λ are rare. Figure 4 is a gnomonic projection of the observed forms; it shows that the common form γ($\bar{1}$51), with its complex symbol and small reticular density, is in simple zonal relation to the principal forms.

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[5] *Winkeltabellen*, Berlin, **1897.**

Optics. The optical elements of the green pyroxene were obtained from a thin section mounted on the universal stage and by the immersion of whole crystals and crystal grains. The plane of the optic axes lies in the plane of symmetry; Z (acute bisectrix) lies in the obtuse axial angle β, inclined to the c-axis at 39°; $2V=62°$; dispersion $r>v$ weak; indices of refraction: $\alpha=1.672$, $\beta=1.679$ (calculated from 2V), $\gamma=1.704$, all ± 0.002. These values are close to those given by Larsen and Berman[6] for a nearly pure light green diopside.

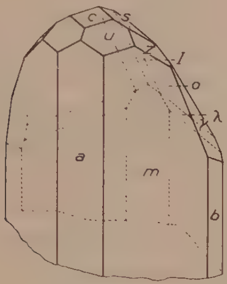

Fig. 2

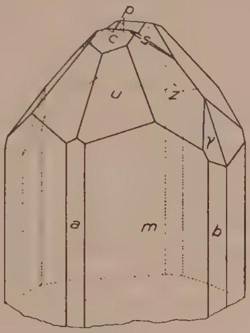

Fig. 3

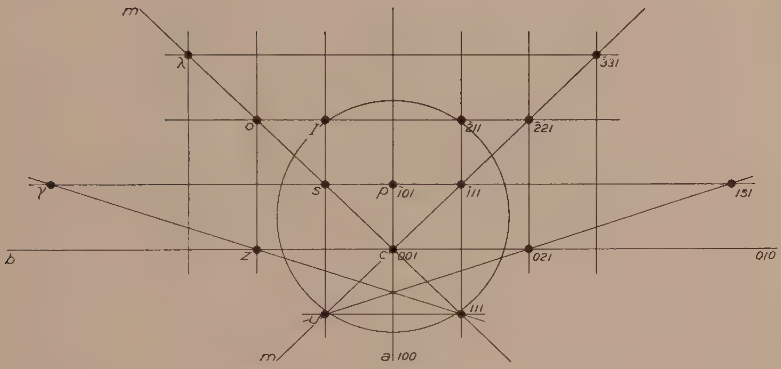

Fig. 4

FIG. 2. Diopside: typical untwined individual.
FIG. 3. Diopside: typical twin.
FIG. 4. Diopside: gnomonic projection showing accepted forms.

Composition. An analysis by F. A. Gonyer, undertaken mainly to test for the presence of chromium, shows that the pyroxene is an unusually pure diopside.

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[6] *U. S. Geol. Sur*., Bull. **848**, p. 243, no. 15, 1934.

	1	2
SiO_2	53.10	55.55
TiO_2	0.17	—
Al_2O_3	2.55	—
Fe_2O_3	0.00	—
Cr_2O_3	0.00	—
FeO	0.97	—
MnO	0.08	—
MgO	17.25	18.52
CaO	25.80	25.93
H_2O	0.04	—
	99.96	100.00

1. Green diopside in limestone xenolith, near South Canyon, E. side of Organ Mts. 15 miles S. of San Agustin Pass, New Mexico.
2. $CaMgSi_2O_6$.

MINERALS IN BATES LIMESTONE, LEWISTON, MAINE*

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INTRODUCTION

Location.—The city of Lewiston is located in the southwestern part of Maine, in Androscoggin County, on the left bank of the Androscoggin. The type locality of the Bates limestone is represented by the City quarry which is located in the southern part of Lewiston, in a low hill known locally as "West Rose Hill." This quarry is along the Brunswick division of the Maine Central Railroad, about one mile southeast of the Lewiston Lower Station. Another outcrop of the Bates limestone is to be found about one-half mile north of the City quarry, along the same railroad at Cedar Street. The Martin quarry, where the Bates limestone is worked, is about three-quarters of a mile south of the City quarry. In these three locations the Bates limestone shows the same general structural and mineralogical characteristics. Igneous intrusions of varying types occur in all three locations.

Local Geology.—The Bates limestone is exposed in the City quarry in a working face which is about 300 feet long and about 60 to 75 feet high. Numerous smaller abandoned pits are to be found on the northwestern slope of West Rose Hill. The Cedar Street location has as great a linear extent as the City quarry but is not as well exposed vertically. The Martin quarry is not as extensively developed as the City quarry. Pegmatites and basic dikes are very common in the City quarry, but the later intrusions are missing at both the Cedar Street and Martin quarry locations.

The Bates limestone has been metamorphosed but bedding planes are still visible. The thickness of the beds varies from a fraction of a foot to several feet. The general strike of the quarry rocks is northeast and the dip northwest. The dip increases rapidly in the immediate vicinity of West Rose Hill. Differences in mineral composition in the various beds are brought out beautifully by differences in weathering. At least five different mineralogical zones have been noted.

IGNEOUS INTRUSIONS IN THE LIMESTONE

Leucocratic Dikes.—Two large masses of pegmatites and numerous smaller pegmatitic and aplitic veinlets cut the limestone at the three localities indicated. The larger masses of pegmatites are made up of large feldspar crystals, muscovite, some long, narrow, blade-like forms of biotite and large crystals of schorl. Some of the pegmatite zones show abundant graphite.[1]

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* Paper read before the *Mineralogical Society of America* at the New York meeting, December 28, 1935.

Aplitic dikes may be seen in abandoned pits in West Rose Hill, in the City quarry proper, and at Cedar Street. In the City quarry minor faults in the aplite have been noted. Numerous small stringers of quartz were given off by these aplitic intrusions. In some of these quartz veins pyrrhotite and graphite have been found.

It should be kept in mind that the Lewiston area is only a few miles east of the famous Mount Apatite pegmatite region, and a few miles west of the Topsham pegmatite locality. An incomplete study of the sequence of formation of the pegmatites indicates that there were two, possibly three, periods of invasion by the acid dike rocks.

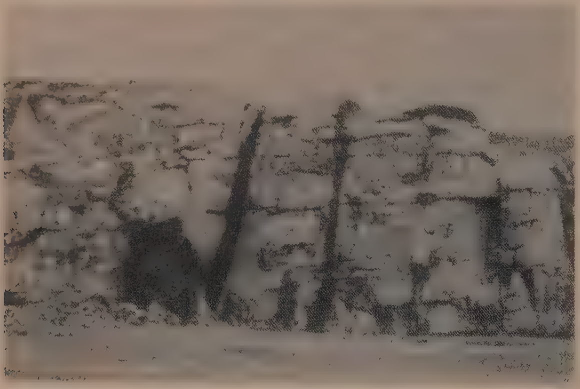

FIG. 1. A portion of the Lewiston City quarry showing trap dikes numbers 5 (left) and 6 (right). Height of quarry, 65 feet, distance between the dikes, 23 feet.

Melanocratic Dikes.—There are at least 16 basic dikes in the West Rose Hill area and seven of these are exposed in the present working face of the City quarry. Some of these basic dikes are two to four feet wide, the largest being 16 feet in width. Some of the dikes show hard, baked zones, and others a zone of loose or soft rock in contact with the limestone. Some of the baked zones are highly discolored. Most of the dikes show phenocrysts of feldspars and others have pyriboles and olivine phenocrysts. Some of the dikes, especially those in the abandoned pits, show typical vertical and transverse fractures with subsequent "step" development. The dikes have been numbered in order that the later discussions may be clearer. Those shown in the illustration are dikes Nos. 5 and 6. They are about 23 feet apart. Dike No. 5 is badly weathered along the contact, but No. 6 shows a chilled zone. Studies made in 1930 showed a north-south fault in the upper part of dike No. 6 with displacement about equal to the thickness of the dike. This displacement is not now shown in the quarry face. Dike No. 8, about 100 feet south of dike No. 6, is faulted near the quarry floor.

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[1] Fisher, Lloyd W., Graphite in Pegmatite: *Am. Mineral.*, vol. **19**, pp. 169–177, 1934.

Some of the basic dikes show chilled zones against the limestone but others show a very sharp contact. Many of the chilled zones are yellowish brown in color but others are purplish black. One of the largest dikes shows a displacement equivalent to the width of the dike. There are numerous smaller offsets in both basic and acidic dikes. There is also one multiple dike. It is suggested that these dikes represent several closely related invasions of the same basic magma in fractures in the Bates limestone.[2]

Summary of the Geologic Sequence.—The Bates limestone cannot be traced for any great distance along the line of strike because of heavy glacial cover and the past building activities in the immediate vicinity. The limestone appears, however, to represent a lens in a larger series of rocks. A knowledge based on field studies indicates the following probable sequence of formations and events in the environs of Lewiston.

Post Silurian	Trap dikes (youngest in the region)
	Pegmatites, aplites and granites
Cambro-Ordovician?	Tacoma Series
	Sabattus garnet schist
	Minwah limy gneiss
	Hill Ridge biotite schist
	Stetson Brook limestone
	Thorncrag limy gneiss
	Bates limestone
	Androscoggin gneiss and schist
Pre-Cambrian	Ortho-gneisses.

Pegmatites and basic dikes cut all the metamorphosed sediments in the immediate region. The pegmatites appear to be post-Cambrian to Carboniferous in age. The trap dikes are the youngest rocks of the region and are possibly post-Paleozoic.

DESCRIPTION OF THIN SECTIONS

Limestones near Pegmatites.—Slides made from specimens taken about nine inches apart in a limestone bed, four inches above the contact with the graphite-bearing pegmatite, show a number of interesting features. Calcite plates are numerous in some of the slides and are subordinate to brown mica in others. Twinning lamellae in the calcite are not bent or curved. Scapolite grains are fairly common and are, in general, almost completely surrounded by calcite. Graphite is quite abundant in some of the slides. In one of the slides graphite flakes are arranged in a streak suggesting a conduit for the producing materials. There are scattered feldspar grains, most of them being close to the calcium end of the plagioclase series. Tremolite and actinolite have been partially replaced by chlorite. These prismatic minerals show frayed ends against the adjacent minerals. Diopside is more common than either actinolite or tremolite, and is fairly fresh. Clinozoisite is less abundant than the amphiboles and pyroxenes, but more abundant than feldspar and scapolite.

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[2] A paper on the trap dikes of the Lewiston City quarry is being prepared by Wendell Crawshaw.

The biotite plates in the slides, from specimens near the pegmatite, show a number of interesting features. In one slide there is a very definite foliation of the plates and in others the foliation is either weak or lacking. Where foliation is strong other prismatic minerals, such as diopside and actinolite, have been developed at approximately 45 degrees to the long axis of the mica. Zircon is the chief accessory mineral. Apatite, in small, bluish grains is sparingly found.

In some of the slides, taken from specimens obtained from the City and Martin quarries, amphiboles and pyroxenes appear to be segregated into zones, although the individual minerals are not oriented in any definite direction. In specimens where such apparent zoning is noted, graphite and pyrrhotite are fairly common. Both these accessory minerals are developed in thin veinlets or along the cleavages of earlier minerals. Calcite plates are fairly rare in these specimens of zoned pyriboles.

A highly silicified limestone is represented by slides taken north of dike No. 5 in the City quarry. In slides of this type of limestone quartz occurs in two forms; as zones of granulated quartz in which very few adjacent grains extinguish at the same time, and as elongated, fractured and strained quartz. In one of the slides there are four zones of crushed and three zones of elongated quartz. Chlorite is moderately abundant at the contact between two of the zones. Zircon is enclosed in some of the chlorite suggesting the formation of this latter mineral from biotite. One nearly perfect euhedral grain of vesuvianite occurs with the elongated quartz. The crushed zones show some feldspar belonging to the albite-oligoclase end of the plagioclase series. There is no calcite in the four slides of this type of limestone.

Contact Types.—Two sets of slides representing contact action of the basic dikes on the limestone were also studied. The contact of trap dike No. 6 with the limestone shows the development of much biotite. The plates and flakes are well oriented. Foliation is approximately at right angles to the contact. The oriented biotite shows a fairly wide zone in the slide, but gives way rather abruptly to a zone in which zoisite, feldspar and quartz are the chief minerals, in the order named. This zone is succeeded by one composed chiefly of calcite plates in which there are metacrysts of diopside, a few slender needles of actinolite, replaced by chlorite, and some graphite. Ten feet north of the contact with dike No. 6 calcite is more abundant, chlorite is more scattered throughout the slide, and biotite plates are not oriented. Amphiboles and pyroxenes are next in importance to calcite. The boundaries of the minerals in this zone are more rounded than at the contact. In both cases, near the dike and at a distance from it, graphite shows no apparent preference for a host mineral. Accessory minerals are vesuvianite, zircon, and titanite.

An entirely different contact condition is noted on the south side of dike No. 5. A fairly large area of strongly pleochroic tourmaline comes in contact with the dike. Vesuvianite is very abundant near the contact and the contact zone is more highly altered than that of dike No. 6. The biotite plates of dike No. 5 are more thoroughly chloritized than at dike No. 6.

General Conclusions

The mineral associations noted in the different zones in the limestone suggest that the Bates limestone was originally an impure magnesium carbonate formation. Various types of metamorphism have transformed some of the original differences into different relative proportions of the minerals in the same bed, and into different mineral assemblages in adjacent beds. The development of calcium and magnesium silicates, as diopside, chlorite and zoisite in fairly large amounts, and tremolite, green hornblende and actinolite, in smaller amounts, suggest a rearrangement of original chemical constituents of the limstone. Scapolite, vesuvianite and tourmaline, the latter only occasionally, indicate additions from the intruding magmas. The abundance of quartz veins near some of the trap dikes suggests introduced material. Occurrences of graphite in the pegmatite, and of graphite and calcite, in some of the basic dikes, indicate a slight amount of assimilation by those dikes.

The general lack of parallelism of the prominent prismatic minerals suggest that dynamic metamorphism was not an important factor in the area. In a few of the slides examined plates and blades of biotite show parallel arrangement. This might be due to pressure or to the preservation of biotite in streaks or lenses originally rich in that mineral in the sediments. The zonal arrangement of some of the minerals, as diopside, zoisite and biotite, noted especially in hand specimens, might have been inherited from the original sediments. Granulation of quartz is noted in only a few of the slides and all of these represent specimens taken from near pegmatitic or aplitic intrusions. The bending of mica plates and the development of calcite twinning planes are not common. It thus appears that dynamic metamorphism is not the controlling factor in the formation of minerals now occurring in the Bates limestone.

There are no pronounced metamorphic aureoles around either the acid or basic intrusives, but the presence of vesuvianite, scapolite and tourmaline, as noted above, suggest introduced materials. No well developed garnet zones are found associated with the basic dikes. This fact together with the observation that most of the trap dikes show chilled borders, indicate a rather low temperature for the invading basic material.

The close proximity of the large pegmatite dikes of Mt. Apatite, six miles west of the City quarry, the Topsham pegmatite, about twelve miles east, and the Woodbury granite, four miles to the south, suggest the presence of a large granitic batholith underlying the Lewiston area. The presence of certain minerals foreign to the limestone is accounted for by assuming the introduction of materials by solutions and gases from this underlying batholith.

A medium to low grade of metamorphism is suggested by the suite of minerals encountered, and by the development of a crude, crystalloblastic texture of some of the minerals that form at moderate temperatures. In some of the slides two generations of biotite follow different planes of foliation which are at angles to the plane of foliation followed by the amphiboles and pyroxenes. Two-fold metamorphism is suggested by these features.

It is believed that the initial change in the minerals of the limestone was caused by the heat, gases and possibly solutions given off by the underlying granitic batholith. This contact metamorphism was then followed, on a smaller scale, by the intrusive action of the pegmatites, aplites and associated quartz veins. The basic dikes are the youngest rocks in the region and their injection apparently caused very little change in the limestone.

NOTES AND NEWS

A PECULIAR TYPE OF ZONING IN FELDSPAR

JOSEPH M. TREFETHEN, *University of Missouri, Columbia, Mo.*

INTRODUCTION

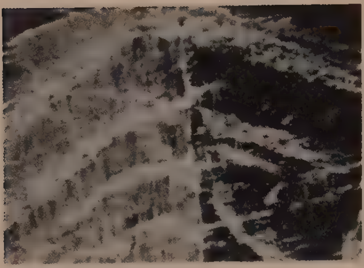
In connection with petrographic studies of the Lincoln Sill, southeastern Maine, a peculiar type of zoning was discovered, which, so far as the author is aware, has not been described in the literature. It is the purpose of this paper to describe and illustrate this peculiar zonal structure.

LINCOLN SILL

The rock from which the zoned feldspars were obtained is a peculiar syenite porphyritic which extends inland in a northerly direction for some fifty miles from Squirrel Island. Squirrel Island lies just off shore from Boothbay Peninsula and about forty miles east of Portland, Maine. The sill stands nearly vertical and is concordant, for the most part, with the regional structural trends. The sill is intruded throughout most of its length by granite and associated pegmatite. The average width of the zone of outcrops is probably close to half a mile. The prevalent type of syenite has a foliated structure due to parallelism of the biotite, which is the principal constituent of the groundmass, and to a lesser extent, hornblende. The zoned feldspars, varying in size, but averaging close to an inch in length, are for the most part aligned parallel to the foliation.

ZONING

The zoned feldspars are dark colored, varying from a dark gray to dark bluish tint, with alternating zones of lighter feldspar. The dark color seems to be due chiefly to minute inclusions which tend to be localized along certain of the zones. The identity of these minute inclusions is uncertain, but in part they appear to be rutile and hornblende. They vary from minute brownish globules, arranged in lines and frequently coalescing to form tiny rods, to well defined rods of a faintly pleochroic greenish tinted mineral with slightly inclined extinction, probably hornblende. The feldspars are for the most part orthoclase and microcline with considerable intergrowth of albite. The zoning of the more massive phases of the syenite appears to be the not uncommon oscillatory type. It is the author's interpretation that the minute inclusions just described may be replacements of the feldspar, localized along certain of the zones, perhaps because of slightly more favorable composition, possibly a slightly greater soda content.



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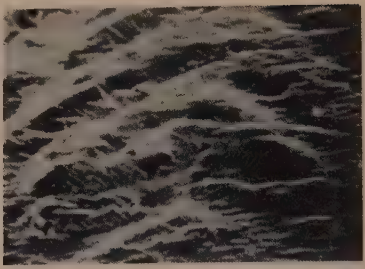

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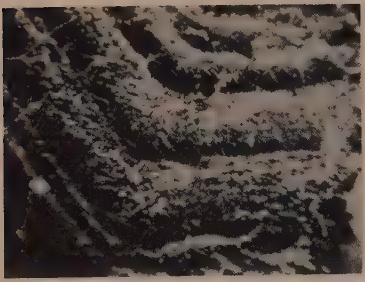

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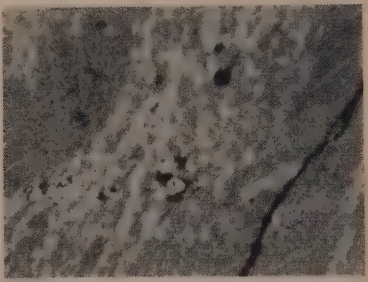

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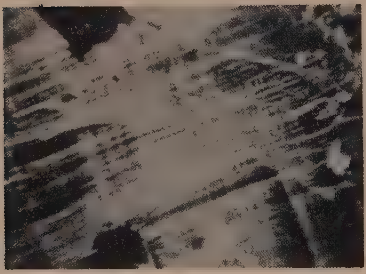

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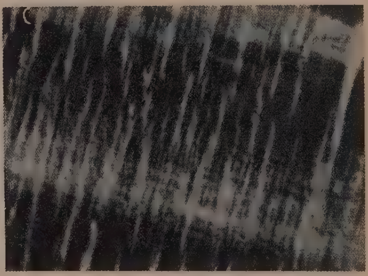

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Fig. 1. Perthitic intergrowth showing zonal structure. ×15.
Fig. 2. Perthitic intergrowth showing zonal structure less perfectly developed. ×15.
Fig. 3. Perthitic intergrowth showing zonal structure. ×15.
Fig. 4. Detail of Fig. 3. ×45.
Fig. 5. Perthitic intergrowth showing zonal structure. ×15.
Fig. 6. Detail of Fig. 5. ×45.

Besides the type of zoning just described, which is not unusual, a type of zoning was noted in the more foliated types, dependent upon the localization of perthitic intergrowths. This was observed particularly in the feldspars from the sill rock close to granitic intrusions. This type varies from clearly defined zones to much more irregular intergrowths, which, nevertheless, maintain a general zonal relationship within the crystals. This type is shown in various degrees of development in the accompanying figures.

Origin of Perthitic Zoning

The author is frankly at a loss to account for the localization of the intergrowths along zones. It might be suggested, however, that the later intrusion of the granite, which probably followed closely after the intrusion of the syenite, either maintained the initial heat of the syenite or added new heat, so that the later cooling was delayed, with the resultant unmixing of the albite from solid solution forming the perthitic intergrowths along those zones particularly rich in the albite molecule. This suggestion is analogous to the suggestions of Harker[1] concerning the formation of perthitic intergrowths during retrograde metamorphism; and if the intrusion of the later granite was accompanied by differential stresses, as appears to be the case, this might favor the separation of the perthitic intergrowths.

Acknowledgement.—The author wishes to thank Professor A. N. Winchell for criticizing the manuscript.

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[1] Harker, Alfred, *Metamorphism*, p. 351, 1932.

AMYGDALOIDAL DIKES

Robert S. Moehlman, *Harvard University, Cambridge, Mass.*

Although amygdules are much less common in dikes than in lava flows, amygdaloidal dikes have been described from various localities.[1] The Colorado occurrence here described is unusual in that plagioclase feldspar is present in some of the amygdules.

The San Juan mountains of southwestern Colorado are composed principally of Miocene volcanic rocks.[2] Seven miles west of the town of Ouray is the Stony Mountain-Sneffels Peak stock of gabbro-diorite. Associated with the stock are andesitic dikes one to fifty feet wide, intruding the volcanic rocks. Microscopic examination shows the dominant constituent of the dikes to be plagioclase feldspar in the andesine and oligoclase ranges. Some of the dikes contain minor amounts of quartz and orthoclase. The primary mafic minerals, hornblende and augite, have been almost completely altered to calcite and chlorite. Small amounts of secondary epidote and sericite occur locally.

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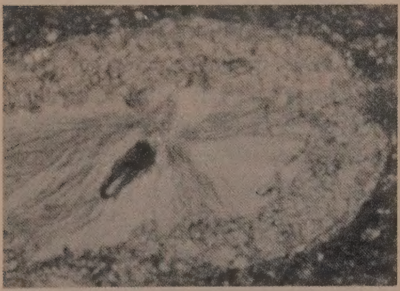
[1] Morris, F. K., Amygdules and pseudo-amygdules: *Bull. Geol. Soc. Am.*, vol. **41**, pp. 383–404, 1930.

[2] Cross, W., and Larsen, E. S., *U.S. Geol. Survey*, Bull. **843**, pp. 50–53, 1935.

Practically all the andesite dikes contain vesicles, most of which are filled with chlorite and calcite. In Fig. 1, a large, radial growth of calcite is in the center of the vesicle, surrounded by many rosettes of chlorite; on the border of the vesicle is more calcite.



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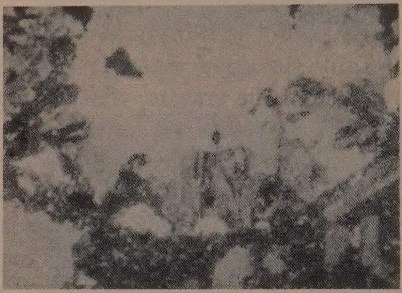

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Fig. 1. Vesicle filled with radial calcite surrounded by chlorite. Crossed nicols. ×8.

Fig. 2. Vesicle filled with calcite, quartz and plagioclase. Crossed nicols. ×10.

Plagioclase was observed in the vesicles of one member of the "Wheel of Fortune" composite dike, a porphyritic andesite exposed in Canyon Creek. Microscopic examination indicates this porphyritic andesite is really transitional between andesite and quartz latite, since the fine-grained groundmass consists of an intergrowth of quartz and orthoclase with some minute plagioclase laths and chlorite. The plagioclase phenocrysts are heavily sericitized oligoclase. The mafic minerals have well-nigh been completely altered to calcite and chlorite.

Locally, vesicles make up more than 5 per cent of the andesite porphyry. The plagioclase in the vesicles is albite-oligoclase and grows radially from the walls toward the center of the vesicle. In Fig. 2, the plagioclase crystals are perched directly on the dike material and also on an intermediate filling of quartz crystals; the interior of the vesicle is filled with calcite.

The presence of plagioclase in the amygdules suggests that higher temperatures prevailed than is ordinarily the case in the formation of amygdules. A deuteric, or late magmatic, origin with nearly magmatic temperatures seems likely for the minerals in the vesicles. The width of the dike in Canyon Creek where the plagioclase-bearing vesicles are found is several times greater than it is a few hundred feet up on the canyon walls. This rapid increase in width of the dike downward suggests that the Canyon Creek exposure is close to a larger intrusive body. Proximity to an underlying large body of magma would account for the higher temperatures prevalent when the vesicles formed. The exposure of the dike in Canyon Creek is nearly 4000 feet below Sneffels Peak, which is composed of a gabbro-diorite stock intruded at essentially the same time as the dikes. The minimum depth of cover was thus nearly a mile, making for a substantial confining pressure.

Morris has cited a number of amygdaloidal dikes and sills where the gases which made the vesicles were distilled from coals and other rocks rich in volatiles.[3] In the Colorado occurrence here described, no source is apparent for introduction of volatiles, and the gases are considered to be of magmatic origin.

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[3] Morris, F. K., *op. cit.*, pp. 383–404, 1930.

BOOK REVIEW

ESSAI DE DÉTERMINATION DES PROPRIÉTÉS OPTIQUES D'UN MINÉRAL PAR LA MESURE, EN LUMIÈRE PARALLÉLE OBLIQUE, DES RETARDS EN DIFFÉRENTS POINTS D'UNE LAME CRISTALLINE. J. Mélon. (Thése présentée à la Faculté des Sciences de l'Université de Liège.) Liège, **1934.** 108 pp., 21 figs.

In recent years American mineralogists and petrographers have begun appreciating the Fedorov stage as an excellent tool that can be put to use in various ways (optical determination of feldspars and of other minerals, double dispersion method, petrofabrics, etc.)

In the present treatise J. Mélon shows that the Fedorov stage can be utilized in still another way. He shows that it is practically possible to determine in thin sections the optical angle (2V) and all the refractive indices of a mineral, simply by measuring the retardation along several directions of the mineral. The measurements are made on a Fedorov stage with either a quartz wedge or Berek's compensator.

The exact formulae for the evaluation of the experimental data are very complicated, and in most cases only approximate formulae are therefore given. This has the advantage of materially simplifying the computations without much loss in accuracy (it should be borne in mind that the observations made with the Fedorov stage are accurate only to 1°).

Although theoretically the mineral grain may have any orientation, there are, nevertheless, distinct practical limits to the method. Results obtained from mineral grains in unsuitable positions are thus of little or no practical value. The method of Mélon cannot, therefore, generally replace any of the other methods of determining 2V and the indices of refraction, but everybody who works with the Fedorov stage should familiarize himself with the method, for it is as far as I know the only method permitting a determination of the refractive indices of a mineral *in a thin section*. A knowledge of this method may therefore, in special cases, prove itself very useful and convenient.

Tom. F. W. Barth

Mineralogisk Institutt, Oslo.

NEW MINERAL NAMES

Lapparentite

H. Ungemach. *Bull. Soc. Franc. Min.*, **58**, pp. 209–213, 1935.

Name: In honor of Jacques de Lapparent, Director of the Institut des Sciences géologiques de Strasbourg, as well as his father, Albert de Lapparent.

Chemical Properties: A hydrous sulfate of alumina. $Al_2O_3 \cdot 2SO_3 \cdot 10H_2O$. Analysis: Al_2O_3 20.91, Fe_2O_3 3.06, SO_3 35.81, H_2O 40.35. Sum 100.12. Very soluble in cold water. Alum taste.

Crystallographical Properties: Monoclinic, habit prismatic, sometimes almost acicular. $a:b:c=0.2919:1:0.2415$. $\beta=85°10'$. $b:m=73°47'$, $c:011=13°32'$. $c:p$ 38°46'. $c:p$ 42°43'.

Physical and Optical Properties: Colorless, limpid.

Occurrence: Found in cavities in coquimbite mixed with chalcanthite and associated with sulfur. Resembles gypsum.

W. F. F.

Paracoquimbite

Ibid., pp. 165–190.

Name: A name given to a rhombohedral form of coquimbite. A comparison is given below.

	Coquimbite	Paracoquimbite
Sym	Hexagonal holohedry	Rhombohedral holohedry
c	1.5643	4.6928
Cleavage	$10\bar{1}1$ imperfect $10\bar{1}0$ barely perceptible	$01\bar{1}2$ and $10\bar{1}4$ imperfect
c	17.0 Å	51.1 Å
a	10.8 Å	10.9 Å
No. molecules in unit cell	4	12
G.	2.096	2.109–2.117
Analysis	Al_2O_3 tr.	Al_2O_3 tr.
	Fe_2O_3 28.94	Fe_2O_3 29.79
	SO_3 42.37	SO_3 41.38
	H_2O 28.48	H_2O 28.69
H_2O at 105	46.8%	44.88%

W. F. F.

Roy Jed Colony, associate professor of geology at Columbia University, died on March 26 at the age of sixty-six years.

Dr. A. E. Alexander, mineralogist at the Buffalo Museum of Science, has been appointed petrographer in the ceramic laboratory of the Electric Auto-Lite Company, of Toledo, Ohio.

Authors desiring to publish articles in *The American Mineralogist* are urged to complete their manuscripts and to send them to the Editor before leaving for the summer. This will insure an early appearance in one of the summer or fall issues of the Journal.